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DIASTROPHISM AS THE ULTIMATE BASIS OF CORRELATION

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There are many and diverse views relative to the nature and the causes of diastrophic movements. To keep as largely as may be on common ground, most of these divergencies of view may be set aside as immaterial to our present purpose. We may all agree that the fundamental factors of the case are a lithosphere with a deformable surface, a liquid, covering part of this surface and determining erosion and sedimentation, and a gaseous envelope. We may easily agree that the outer part of the lithosphere is solid and has a sufficient measure of rigidity to maintain the surface inequalities. I do not see that we need to agree as to the causes of deformation. In some sense, I do not see that we need even to agree as to just what the absolute movements were, i. e., I do not see that it is material for us here to know whether the deformative movements were shrinkages, or expansions, or lateral shifts, provided we agree as to the general nature of their effects on the agencies at work on the surface of the lithosphere. We do not need to entertain the same conception of the nature of the earth's interior, if we are at one as to the working conditions which have prevailed on its surface.

No doubt we can easily agree on the present great working factors: (1) abysmal basins occupying about two-thirds of the earth's surface, bordered by terrace faces rising at angles of 2° to 5° for say 12,000

feet to a quite definite terrace-angle about 100 fathoms below the sea-level; (2) continental platforms whose upper faces slope gently up from this angle to the coast-line and thence ascend into the various reliefs of the land. If we thus agree that the upper face of the continental platform is bounded by the edge of the continental shelf, and that this edge is equally the boundary of the abysmal basins, whether the waters overlap the edge or not, we may also agree that the edge of the oceanic waters, whether they agree with the edge of the abysmal basins or not, form the chief line of demarkation between the great erosions and the great depositions the world over. It is not the only line of such demarkation, to be sure, for degradation gives place to aggradation at many other local horizons, but in this discussion let us agree to deal only with factors of the larger order and to neglect incidentals; let us deal with body deformation, rather than local or provincial warpings. We all recognize further that the sea-level is not only a dividing plane between two great divisions of physical agencies, but between two great biological divisions.

To this list of agreements, there are two other propositions which we cannot add quite so unhesitatingly, because we need to weigh them well, and if we cannot all agree respecting them, we must agree to differ, for they are fundamental to the further discussion. These relate to the effects of body deformation on the relations of land and sea.

If deformation were confined to the abysmal bottoms and were compensatory, no effect would be felt on the relations of land and sea. If deformation were confined wholly to the interior of the continents, it would be similarly ineffectual. Deformations so limited are, however, likely to be only provincial, and fall outside our discussion.

There remain two conceptions of general or body deformation between which choice must be made. In the one, the deformations are supposed to be indifferent to their predecessors, and to disregard the configurations produced by previous deformations. Their successive effects upon continental outlines and basin capacities are thus heterogeneous and the combined results irregular and uncertain. It is not clear to me how they can be made a very trustworthy basis of systematic correlation. The submergent phase of one continent

or fraction of a continent may, in this case, be contemporaneous with the emergent phase of another continent or fraction of a continent, and the progress of events on one continent is as likely to be contrasted with those of another continent as to fall in with them co-ordinately.

According to the other view, deformations are inheritances, one of which follows another in due dynamical kinship. The succession is therefore homogeneous and the results co-ordinate. If, for example, the first depression of the abysmal basins was due to the superior specific gravity of the basin-bottoms, this specific gravity remained and participated in the next deformation. If the continental masses, at the outset of continental formation, were relatively low in specific gravity, this low specific gravity was handed down to later periods and helped to renew deformation of the same phases in the same regions. Under this view, ocean basins and continental elevations tended toward self-perpetuation. It is not assumed that this prevented shell crumplings, provincial warpings, or block movements of diverse phases within the continental or the abysmal areas, for these might obviously be necessary effects of the general deformative movements, or at least inevitable incidents connected with the dynamics lying back of them.

A choice between these two conceptions is imperative to this discussion, as they lie at the parting of the ways in the interpretation of the larger events of geologic history. I accept the second view with much confidence. It should be more fully qualified respecting the incidental accompaniments just mentioned, but time does not permit.

According to this view, each great diastrophic movement tended toward the rejuvenation of the continents and toward the firmer establishment of the great basins. The distinction between continent and basin must not, however, be interpreted on the superficial ground of the water-line, for the water-line merely shows that the basin is over-full, just full, or under-full, as the case may be. The average water-line undoubtedly helps to give a definite terrace border to the abysmal basin, but the water-line freely abandons this and often is far from coinciding with it.

The base-leveling processes have shown that they are able to lower the continents approximately to the sea-level in a fraction of

geologic time. The continents would therefore have long since disappeared, if they had not been rejuvenated by renewed relative elevation or the withdrawal of the sea. I am able to find no evidence of lost continents. There are submerged margins, and matter has been carried continent-ward from denuded borders. There are some submerged dependencies and inter-continental connections. There are also some rather deeply submerged ridges that probably connected the present continents at remote stages in their history. In the earlier eras, when the differentiation of platforms and basins was less advanced, ridges which have since been submerged are perhaps recognizable. In the interpretation of the earlier periods, these should probably be restored as continental connections. In the earliest known ages, these may have been rather numerous and their combined area considerable, but these seem to me to be only qualifying features which, by the natural place in evolution which they fill, support, rather than weaken, the general conception of a systematic succession of deformations in which the offspring of each is the parent of the next, and in which both continents and ocean basins were progressively segregated and unified.

I trust that many of you will agree that, in general, the relatively upward movements of diastrophism have been located continuously in the continents, and the broad downward movements continuously in the ocean basins, and that, setting aside incidental features, the dominant effect of the successive diastrophic movements has been to restore the capacity of the ocean basins and to rejuvenate the continents. This conclusion seems to me to be strongly supported by the general course of geologic history, wherein sea-transgressions and sea-withdrawals have constituted master features. Perhaps our firmest ground for this conviction is found in the present relations of the continents and the sea basins. If heterogeneity had dominated continental action in the great Tertiary diastrophisms, the results should stand clearly forth today. Some continents should show recent general emergence, while others should show simultaneous general submergence. The dominant processes today should be those of depressional progress, on the one hand, and those of ascensional progress, on the other. As a matter of fact, all the continents are strikingly alike in their general physiographic attitude toward

the sea. They are all surrounded by a border-belt, overflowed by the sea to the nearly uniform depth of 100 fathoms. These submerged tracts are all crossed by channels, implying a recent emergent state. None of the continents is covered widely by recent marine deposits, and yet all show some measure of these. Wide recent transgressions in one part do not stand in contrast with great elevations in another. Even beyond what theory might lead us to expect, when we duly recognize the warpings incidental to all adjustments, the recent relations of the continents to the seas conform to one type. The 10,000,000 square miles of continental margin, now submerged, is distributed around the borders of all the continents with a fair degree of equability. May we not, therefore, agree that in the world-wide phases of diastrophic movements, the basins have been additionally depressed and the continents repeatedly rejuvenated.

It is important that we should agree, or agree to disagree, on one further point. Have diastrophic movements been in progress constantly, or at intervals only, with quiescent periods between? Are they perpetual or periodic? The latter view prevails, I think, among American geologists. This view has acquired especial claims since base-leveling has come to play so large a part in our science, for it is clear that the doctrine of base-leveling is specifically inconsistent with the doctrine of perpetual deformation, for the very conditions prerequisite to the accomplishment of base-leveling involve a high degree of stability through a long period. The great base-levelings, and the great sea-transgressions, which I think are little more than alternative expressions for the same thing, have, as their fundamental assumption, a sufficient stability of the surface to permit base-leveling to accomplish its ends. Shall we not therefore agree that there has been periodicity in the world-warping deformations? Let this not be held with such exclusiveness that we fail to recognize duly the effects of the adjustment of minor stresses, at other times. These may be preliminary or after-effects of the larger movements, or they may be due to local stresses more or less independent of the general body-stresses. These quite certainly have been present, and have produced intercurrent departures from the strict tenor of the great systematic movements.

If there is need for additional argument on periodicity, it may be

found in theoretical considerations, but these we have tried to avoid in the main. Whatever we may regard as the fundamental agencies that give rise to those stresses in the earth which are precedent to deformations, we may easily all agree that the earth opposes some resistance to deformation. There is certainly some rigidity in the body of the earth. According to the fundamental laws of rigidity, the deforming stresses must reach a certain magnitude before a movement can start. Now, if we recall that every such deformative movement, affecting a free surface, in its very nature, throws the resisting crust into an attitude of relative weakness, it follows that, with such progressive easing, the movement will go on until the stress is accommodated and a state of equilibrium essentially restored, after which another period of accumulation is prerequisite to another movement.

If we are agreed on the periodicity of great deformations, it clearly follows that in a quiescent state the base-leveling of the land means contemporaneous filling of the sea basins by transferred matter, and hence a slowly advancing sea-edge which is thus brought into active function as a base-leveling agent. This water movement is essentially contemporaneous the world over, and is thus a basis for correlation. *The base-leveling process implies a homologous series of deposits the world over.* At first these represent the conditions immediately following continental rejuvenation. Later they are succeeded by the deposits representing the modified conditions to which the first stage gives rise, and so on through the series up to the climacteric ones when base-leveling has reached its greatest development. After this a declining series follows. The deposits of the more advanced stages of base-leveling are, as now well recognized by most American geologists, markedly different in physical constitution and physiographic aspect from those of the earliest stages of continental rejuvenation. The criteria for discrimination between these earlier and the later members of the series are indeed of the collective rather than the individual type; they have character as distinctive assemblages of criteria rather than as single or isolated criteria, but they are perhaps all the safer for this composite character.

Correlation by base-levels is one of the triumphs of American geology; correlation by its complement, transgressive deposits on a

base-level, may easily be added, and perhaps on quite as firm or even firmer physical grounds. If we add the biological element the case is immeasurably strengthened, for correlation by cosmopolitan faunas, the very best of faunas for the purpose, is added to the physical correlation. Migration at the climax of base-leveling and sea-transgression is freer and more prompt than at other times. Correlation to the foot, as by an unconformity, may not be practicable, but the precision of correlation by unconformities has more apparent than real value, for the different parts of the same unconformity vary much in time. All distant correlations involve some measure of inexactness, and the more frankly it is made obvious, the less its liability to mislead.

Correlation by general diastrophic movements takes cognizance of four stages: (1) the stages of climacteric base-leveling and sea-transgression, (2) the stages of retreat which are the first stages of diastrophic movement after the quiescent period, (3) the stages of climacteric diastrophism and of greatest sea-retreat, and (4) the stages of early quiescence, progressive degradation, and sea-advance.

(1) The characteristics of the climacteric stage of base-leveling and sea-transgression need little further characterization here, for the function of base-levels is known to all American geologists and the function of great sea-transgression to every stratigrapher and paleontologist. We have in base-leveling conjoined with sea-transgression, just that combination of agencies which is competent to develop the broad epicontinental seas of nearly uniform depth requisite for an expansional evolution of shallow-water life. At the same time, it furnishes broad pathways around and across the continental surfaces for wide migrations and the comminglings that lead to cosmopolitan faunas of the shallow-water type.

(2) The stages of initial diastrophism and sea-retreat find their criteria in the deposits that spring from an increased erosion of the deep soil-mantles accumulated in the base-level period, in the effects of increasing turbidity, in the lessening areas suitable for the shallow-water life, and in the limitation of migration.

(3) The climacteric stages of diastrophism are marked by the stress of restrictional evolution among the shallow-water species; by increased clastic deposition in land basins, on low slopes, and on sea

borders, by great land extension, but often, perhaps dominantly, by diversity of land surface and by liability to climatic severities and diversification. Areally, land life is favored, but it is hampered by the climatic and topographic diversities, and these may prove graver obstacles to migration and intermingling than even the tongues of sea that previously traversed the land surface. Correlation by glaciation in these stages is likely to prove a valuable adjunct, but we must first test our criterion, for we are not as yet quite sure that contemporaneity of glaciation is inferred on reliable grounds. The shallow-water life of the diastrophic stages is driven into narrow border tracts and into local embayments, and is thus forced into special adaptations and into narrowly provincial aspects.

(4) The early stages of quiescence and of base-leveling, with advancing seas, are peculiarly fruitful in biological criteria, for they are marked by re-expansions of the narrowly provincial shallow-water faunas of the previous stages. The progressive development of these provincial faunas and their successive unions with the faunas of neighboring provinces, as these come to coalesce by means of the progressive sea-advances, form one of the most fascinating chapters in life evolution, and give some of the most delicate of criteria for correlation.

This rough outline is quite too meager duly to set forth the criteria of correlation connected with the stages of general diastrophism. It rather suggests them than sets them forth.

It remains to consider the precedence among themselves of the three factors, diastrophism, deposition, and life development.

We are accustomed to look to the life record as our chief means of correlation. Its very high utility is quite beyond discussion. Thoughtful students, however, recognize that the paleontological record is based, in an essential way, on stratigraphy and that it is corrected and authenticated by the precise place the life is found to occupy in the stratigraphical succession. Stratigraphy and paleontology thus go hand in hand, each sanctioning the other. *Diastrophism lies back of both and furnishes the conditions on which they depend.* The relationship is not reciprocal in any radical sense. The life does not, in any appreciable way, affect diastrophism. Deposition has been thought to be related to mountain-folding.

Erosion in one area and deposition in another has been assigned as an initial agency in deformation. While some influence of this kind may be conceded, I think it is rather a localizing influence than a fundamental one. If wrinkling must take place from other causes, quite possibly previous erosion here and deposition yonder may localize the wrinkling. But that is quite apart from fundamentally causing the wrinkling. Reasons are growing yearly in cogency why we should regard the earth as essentially a solid spheroid and not a liquid globe with a thin sensitive crust. I think we must soon come to see that the great deformations are deep-seated body adjustments, actuated by energies, and involving masses, compared to which the elements of denudation and deposition are essentially trivial. Denudation and deposition seem to me clearly incompetent to perpetuate their own cycles. It seems clear that diastrophism is fundamental to deposition, and is a condition prerequisite to epicontinental and circum-continental stratigraphy.

Diastrophism thus seems to me fundamental both to stratigraphic development and life development. Diastrophic action seems to be the forerunner of both these standard means of correlation. It therefore seems to be the ultimate basis of correlation. The criteria of this correlation include at once its own specific criteria, the criteria of stratigraphy as dependent on diastrophism, and the criteria of paleontology as modified by the direct and indirect effects of diastrophism.

CONCERNING CERTAIN CRITERIA FOR DISCRIMINATION OF THE AGE OF GLACIAL DRIFT SHEETS AS MODIFIED BY TOPOGRAPHIC SITUATION AND DRAINAGE RELATIONS[1]

WILLIAM C. ALDEN

Between the limits of the drift sheets of Wisconsin age in southern Wisconsin and northern Illinois and the Driftless Area there is exposed a deposit of glacial drift of pre-Wisconsin age, having certain characteristics and relations which are of some significance in their bearing on the question of the criteria to be regarded as indicating difference of age in glacial drift sheets—a question of prime importance in the study of the Pleistocene deposits.

The drift under discussion mantles the slopes and uplands on either side of Rock and Sugar rivers and extends thence westward to the Driftless Area (Fig. 1). In southern Wisconsin the writer's observations were extended westward to the limit of the drift but in Illinois they were confined to a belt ten to twenty miles wide on each side of Rock River.

The filling of the main valleys is, in part at least, composed of outwash from the glaciers of the Wisconsin stage and this filling is not included in the present discussion. The upland drift consists principally of a sheet of moderately compact, highly calcareous clayey till which is practically identical in character and lithologic composition throughout the area examined by the writer.

In places, especially near the surface, the drift is loose and sandy. About 80 to 85 per cent. of the pebbles and bowlders imbedded in this till, as shown by many observations, and by the average of 71 analyses made by counting, are from the local limestones. About 3 per cent. are sandstones, shales, and quartzites, which are probably mostly of local origin, and about 14 per cent. crystallines of Canadian

[1] Published by permission of the Director of the U. S. Geological Survey. Read before the Geological Society of America, Baltimore Meeting, December 30, 1908.

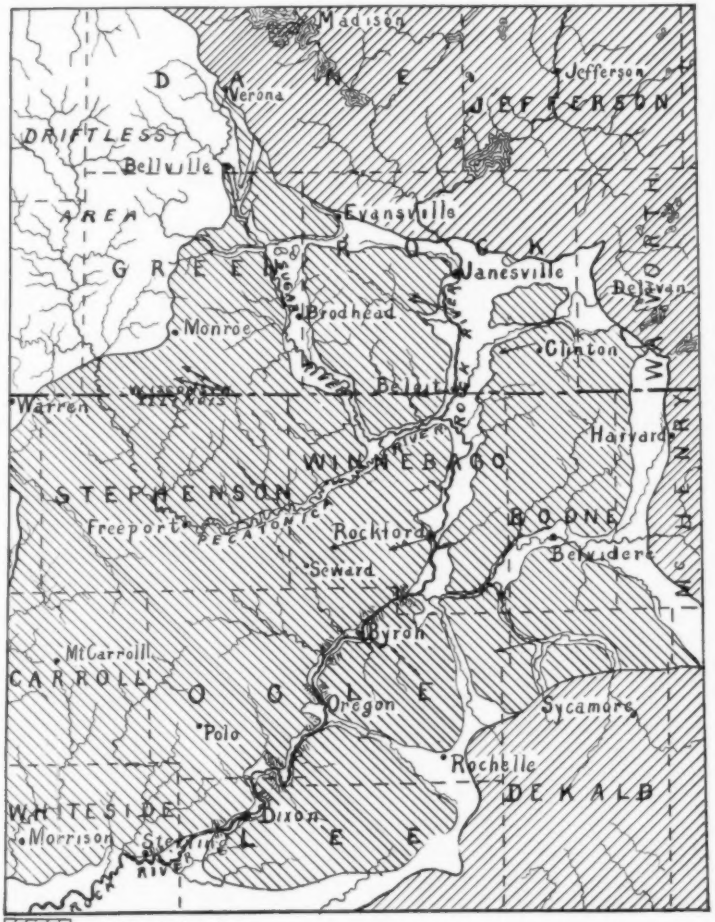


FIG. 1.—Glacial map of portions of southern Wisconsin and northern Illinois. (Boundaries for that part of Illinois not examined by the writer from Frank Leverett, "Illinois Glacial Lobe," *Mon. U. S. Geol. Surv.*, XXXVIII, Pl. XII.)

derivation. The limestone pebbles are mostly from the Galena and Trenton formations,[1] which underlie the drift throughout the greater part of the area, and partly from the Niagara limestone whose west margin lies a few miles east of the Wisconsin terminal moraines. The principal difference in the lithologic composition in the several parts of the area consists of a decrease in the content of Niagara limestone as one goes westward farther from the margin of that formation, with a reciprocal increase in the percentage of Galena and Trenton. Niagara pebbles are, however, seen in almost every exposure westward to the limit of the drift, the average shown by analyses being nearly 24 per cent. of the whole. The presence of this Niagara constituent with an occasional pebble of Devonian rock shows clearly the easterly derivation of the drift which is in consonance with the evidence of direction of the ice movement as shown by striae observed at several places. The striae, as shown upon the map, have bearings shifting from S. 75° W. east of Rock River and near Rockford, to due west at Beloit, N. 62° to 75° W. near Janesville, and N. 35° to 75° W. southeast of Monroe, as the ice closed in about the southeast side of the Driftless Area. At no place has the writer observed this till sheet to be overlain by any deposit other than sand, clayey loam, and loess, which could not have been, or probably was not derived from this drift by weathering or erosion.

It is quite possible, if not probable, that this till is underlain in part at least by older drift, but that question is not here under discussion. So far as the writer has observed there is no good ground for differentiating the drift exposed at the surface into deposits of more than one stage of glaciation. No intercalated soils, weathered zones, vegetal or other fossiliferous deposits are known to separate one part of this drift from another. Such as have been penetrated in wells or otherwise located occur beneath considerable thicknesses of this drift and probably represent an earlier stage of deglaciation.

The drift under discussion is clearly older than that bordered by the Wisconsin terminal moraines on the north and east, and it is believed to correspond in age with the Illinoian drift sheet which covers so large a part of Illinois farther south. There are, however,

[1] The Paleozoic formations are referred to in this article by the names in use for them in eastern Wisconsin by the Wisconsin Geological and Natural History Survey.

certain differences in the topography, amount of erosion, and depth and degree of surficial alteration of this drift in different parts of the area, which are very confusing when one attempts to apply the usual criteria for the discrimination of the age of drift sheets and which might be, and indeed have been considered indicative that this drift represented more than one stage of glaciation. It is the purpose of this paper to point out the differences and to suggest an interpretation of them which may perhaps find application in other areas.

FIG. 2.—Erosion topography on Galena and Trenton limestones thinly covered with Illinoian drift three miles east of Monroe, Wis. Very little if any of the upland plain remains not reduced to slope.

The first of these differences to be considered are topographic. The character of the valley bottoms is to be neglected as due to subsequent filling, only that of the slopes and uplands being considered. In that part bordering Sugar River and extending thence westward to the Driftless Area the surface is much dissected with reliefs of 200 to 300 feet. At no places does a square mile of the upland remain and the drift-mantled slopes show drainage lines at intervals of 10 to 30 rods, which often notch the crests of the divides (Fig. 2). The topography as a whole closely resembles that of the Driftless Area to

the west (Fig. 3). Judging by the *topography* of the slopes and uplands alone one might say that the drift here was as old as the Kansan. Eastward to Rock River there is a little less relief and not quite so much dissection of slope, yet there is but little upland left and the topography looks mature. There are, however, in several places west of Rock River indications in the topography itself that the post-glacial drainage development is not as mature as appears from a more general view. At quite a number of places small drift

FIG. 3.—Erosion topography on Galena and Trenton limestone in the Driftless Area northwest of Monroe, Wis. Very little if any of the upland plain remains not reduced to slope.

dams in the valleys have diverted the drainage to one side where small gorges have been cut through adjacent rock spurs. These drift dams are small and their crests are usually well below the general upland level. The basins above these dams, however, are clearly not due to post-glacial erosion. There is thus positive evidence that the valleys were not entirely filled by drift and subsequently re-excavated, and hence that the present relief is only in small part due to post-glacial erosion. While there is thick drift in many places in the valleys, the upper slopes were usually but thinly mantled with drift

and the apparent maturity is largely due to the fact that the pre-glacial topography was but slightly masked and not wholly buried as it was within the terminal moraines of the later sheets. The post-glacial drainage, with the exception of these slight divergences, has followed pre-glacial lines, and here the gradients of the drift-mantled slopes were sufficiently high to favor rapid erosion.

East of Rock River the area covered by this same drift has a more youthful aspect, being a gently undulating upland plain with slight drumloidal ridges and occasional undrained sags. The borders of the tract are trenched by drainage lines but not greatly dissected. The amount of erosion of this upland, which extends southward to the valley of the Kishwaukee in southern Boone County, Illinois, appears but little greater than in similarly situated tracts within the Wisconsin terminal moraines, and, judging from these features alone, one would be very apt to conclude that the drift east of Rock River was considerably younger than that west of Sugar River, if not younger than that between the two streams.

Passing to the upland prairie west of Rock River in Winnebago, Stephenson, Ogle, Lee, and Whiteside counties, Illinois, one finds extensive, undissected tracts, nearly flat or very gently sloping (Figs. 4 and 5). Only the borders of these tracts, where abrupt slopes drop down to the valleys, appear to be eroded. From this condition there is a gradual transition northward to the rather mature topography between Rock and Sugar rivers. We have thus distinct topographic differences in different parts of the area which affect the interpretation of the glacial history.

On examining the degree of surficial alteration of this drift also notable differences appear. West of Rock River in Illinois, where there is such slight drainage dissection, the drift, beneath the thin coating of stoneless clayey loam or loess which is generally present, exhibits striking evidence of long exposure to leaching and oxidation. In many places but a scattering of pebbles lies between the loess or loam and the weathered surface of the limestone and these pebbles are all of the more insoluble kinds of rocks, mostly dense, fine-grained crystallines, cherts, quartzites, and vein quartz. Where there is a few feet of drift it is generally oxidized to a dark brownish color, is rather compact and sandy, not loose sand, but crumbling when dry into little

chunks, and the calcareous constituents are almost entirely removed. Where greater thicknesses are exposed, such as 5 or 10 feet or more, a very striking condition is revealed (Fig. 6). The body of the drift is found to be fresh, slightly altered, highly calcareous, clayey till, of light buff, pinkish, bluish, or grayish tint, in which the crystalline pebbles are sound with the exception of some of the diorites, or more basic granites. Fully 80 per cent. and often 85 to 90 per cent. of the pebbles in this unaltered part of the drift are limestone and these are

FIG. 4.—Illinoian upland drift plain of remarkably long, gentle, uneroded slope. The drift is probably of moderate thickness, overlain by a few feet of loess and underlain by Galena limestone. Three miles northeast of Seward, Ill.

undecayed and have smooth, clean surfaces, often highly polished and delicately striated. Within two or three feet of the top of the till and the base of the loess, however, there is an abrupt change in character and appearance. Passing upward the drift becomes dark brownish in color, the clayey matrix is found to be nearly or quite leached of its lime carbonate, and the few limestone pebbles which remain are either so rotted as to crumble between the fingers or the surfaces have been roughly etched by solution. In places only a soft yellow powder marks the former position of a limestone pebble. Within a few inches this grades upward into a dark-red layer from

which every particle of limestone including the pebbles has been removed, leaving only a small amount of sticky red clay, the residuum of complete disintegration of the limestone, binding the insoluble constituents, sand grains, quartz, quartzite, chert, and dense, fine-grained crystallines into a compact gritty mass. This layer is usually about 2 feet, sometimes 3 feet in thickness, and the change from the unaltered drift below takes place with remarkable abruptness generally within less than a foot—often within the space of a few

FIG. 5.—Illinoian upland drift plain, five miles west of Rockford, Ill. Galena limestone covered with 1 to 40 feet of drift. There are here extensive tracts of upland and long gentle slope but little affected by erosion.

inches. The red till is not a distinct deposit, for the change is usually gradual, though occurring within so small a distance. If the high percentage of calcareous material present in the unaltered part of the till is supposed originally to have continued to the surface of the deposit, as there is every reason for thinking it did, then this residual layer of insoluble constituents must represent but 20 per cent. of the thickness subjected to alteration. In other words, the 3 or 4 feet of residual till represents the concentration of the insoluble constituents in an original thickness of 15 or 20 feet of unaltered till. Even if for conservatism we consider the calcareous and other soluble

material as comprising but two-thirds of the unaltered drift the amount of alteration accomplished is considerable in reducing a thickness of 9 to 12 feet to 3 or 4 feet of residuum. This is much greater than the amount of alteration of the Wisconsin drift and indicates a much longer time of exposure, a length of time seemingly out of harmony with the amount of erosion which has been accomplished in this part of the area—for this residual drift is well developed where the

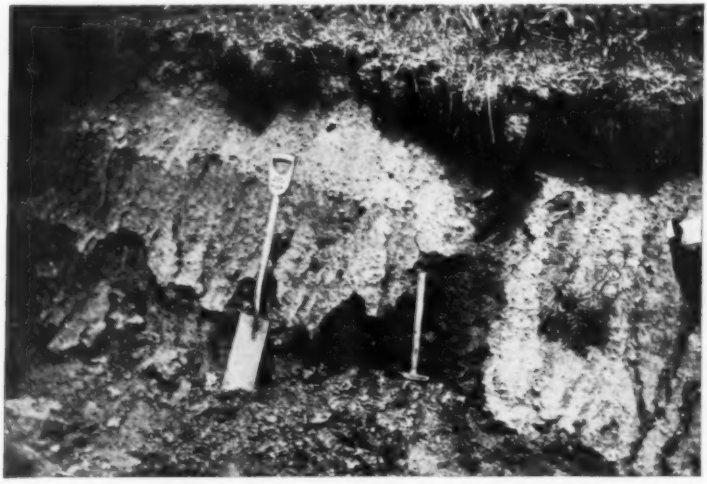


FIG. 6.—Exposure of Illinoian drift one-half mile south of Seward, Ill. The section shows loess 1½ feet—dark-red, residual, weathered Illinoian till from which all limestone pebbles and finer calcareous material have been removed by solution, 2 to 3 feet—buff calcareous till with abundant pebbles of Niagara and Galena limestone. The length of the hammer, 16 inches, shows the zone of gradation from residual to unaltered calcareous till.

plains are least dissected by erosion. We have thus the combination of rather old drift and very young topography.

Added to these confusing conditions, one examining this tract west of Rock River in Illinois, especially along the borders of the upland, and in that part west and northwest of Rockford, frequently finds unaltered till coming right up to the surface or to the base of the thin coating of loess or loam, or else the unoxidized till has only the calcareous material of the clayey matrix leached out to depths of one or

two feet, while the limestone pebbles are fresh and sound. There are also occasional eskers and knolls of fresh limestone drift rising 5 to 25 feet above the surrounding plain of weathered drift. The relations are such that one might easily be led to the conclusion that the old drift sheet was overridden by a later advance of an ice sheet, which was thin and caused but little removal of the pre-existing drift, and which, on melting, left a scattered deposit of fresh drift upon the old.

East of Rock River where the most youthful topography is found the extremes in degree of weathering above noted are less frequently seen, there being the more usual combination of oxidation to a dark buff or brownish color and fairly complete leaching of the fine calcareous elements from the clayey matrix, but without removal of the limestone pebbles, though the surface of such pebbles in the upper part of the zone of weathering may be somewhat etched by solution. In some exposures the upper part of the drift is reduced to the residual condition and a few instances were noted where the matrix was leached of lime carbonate to depths of 10 to 15 feet, but this is rare. The average depth of surficial alteration east of the river is 4 or 5 feet. Were exposures more frequent in the uneroded parts of this upland tract the average amount of alteration might be found to be greater than this.

In the tract between Rock and Sugar rivers where the topographic development appears considerably more mature, and between Sugar River and the west limit of the drift where the amount of dissection seemingly approximates that of the Driftless Area, the drift on the slopes and crest is generally very thin, often little more than scattered pebbles, mostly of the insoluble varieties between the loamy clay soil and the weathered surface of the limestone. In many places, however, especially on lower slopes and in the valleys, considerable thicknesses of drift remain, sometimes 100 to 200 feet or more. Where even a few feet of this till are exposed the unaltered part is found to be the same highly calcareous drift as seen elsewhere. Tests at 25 or 30 exposures show the matrix of the till to be leached of its calcium carbonate to an average depth of about 4 feet, but the limestone pebbles are not removed. This depth includes the thin coating of brown non-calcareous loamy clay which generally overlies the drift

north of the state line. The leached top of the till is usually oxidized to a buff or brownish tint, but beneath this there is little or no evidence of alteration. At a few of the exposures basic crystalline pebbles in the weathered zone are considerably disintegrated but most of the crystalline and limestone pebbles are fresh, clean, and sound, showing little more alteration than in the late Wisconsin drift. Nowhere in this part has the residual condition of weathered drift been found so well developed or at least so well preserved as it is near Rockford, Illinois.

Taken altogether there is in this area of pre-Wisconsin drift a rather confusing lot of differences which must be harmonized if one is to reach any definite conclusion as to the relative age of the drift exposed. The unaltered drift is practically identical in character and lithologic composition throughout, the only differences in the latter being such as would be expected from an ice sheet moving in a westerly direction across the different rock formations which underlie the drift in different parts of the area or immediately to the eastward. The only questionable element is the derivation of quartzite pebbles, which need not be considered in this connection.

The differences in the present topography appear to be due very largely to differences in the pre-glacial topography which in the northwest was only mantled by the drift and not entirely obliterated; and in part to a retardation of erosion in certain parts of the area due to the relocation of Rock River, following the melting of the Illinoian ice sheet.

The character of the pre-glacial topography depends largely on the relations of the limestones and sandstones to the zone of erosion. The greater part of the area, that is, the slopes and uplands, is underlain by the Galena and Trenton limestones. These and the underlying formations have very low dips, curving over the low broad axis of the southern end of the Wisconsin island. Going toward this island, that is, up the low dip, the edges of the formations are beveled off and successively lower formations rise in the zone of erosion. The slopes developed on the limestones were rather long and gentle, but where the friable St. Peter sandstone rose into the higher levels there was more rapid erosion, a steepening of the slopes, and a greater amount of dissection was accomplished. This standstone rose well up in

the slopes north of the state line and here also Rock River cut down into the Potsdam sandstone, so that the uplands of Rock and Green counties west of Rock River were much dissected and almost wholly reduced to slope. East of Rock River, however, the southeasterly dip depressed the St. Peter sandstone in the east slope of the valley and carried it wholly below the bottom of the pre-glacial valley which bordered the eastern upland on the east in Walworth and McHenry counties. This confined the erosion more largely to the horizon of the limestones and as a result there was less dissection east of the river and much of the upland plain was left. Similar conditions resulted from the southward dip south of Pecatonica River on the west side of the Rock Valley. The St. Peter sandstone comes up again locally between Byron and Dixon, Illinois, but here other relations control the final result. The deposition of the drift sheet under discussion mantled these slopes and uplands but, as has been shown, the pre-glacial topography was only masked, not wholly obliterated, so that subsequent drainage for the most part followed earlier courses. Thick deposits were preserved in the valleys, but in the more dissected tracts, especially where the upper slopes were steep, conditions have been favorable for the accomplishment of considerable erosion.

Not only did the character of the pre-glacial topography affect erosion of the drift, but the relocation of Rock River, the master stream, which followed the retreat of the ice front had also some effect. When the glacial margin was melted back to the east side of the pre-glacial Rock Valley above the mouth of Kishwaukee Valley south of Rockford, the accumulated waters from the blocking of the drainage and melting of the ice found outlet across a series of cols and along the intervening valleys between Rockford and Sterling, so that the post-Illinoian stream became located along a new course, that which is now followed between Rockford and the Mississippi. In deepening its valley along this line the river was forced to cut gorges in limestone and sandstone at several points. There is some evidence that this cutting began 100 feet or more above the level of the present stream. Just how much below this level these gorges were cut before the outwash gravels of the Wisconsin stage came in is not known, but it is evident that their erosion must have retarded the work of the main stream and its tributaries throughout the area under discussion.

The fact that almost all of the area west of the Rock and north of the Pecatonica had previously been reduced to slope gave opportunity for considerable erosion there, despite this retardation, but elsewhere the slow process of working back into uneroded uplands had to be undertaken and as a consequence only the margins of the upland tracts have been dissected, while the upland plains, though fairly well drained, are still largely untouched by erosion.

In the relation of the rate of surficial alteration of the drift by leaching and oxidation to the rates of removal of the upper part of the drift by surface wash under these different conditions prevailing in different parts of the area may be found the explanation of the apparent discrepancies noted when attempting to apply the criteria for determining the age of the drift sheet. The discrepancies are apparent rather than real, yet they are none the less confusing. The difficulty is to make the proper allowances and draw the right conclusions.

In the region south of the state line where the extremes of fresh or little weathered drift and of drift reduced to a residual condition are found at the surface or immediately underlying the loess or loamy clay in neighboring exposures, careful examination reveals the fact that in many places at least where the drift is so fresh the topographic relations are such that the weathered upper part may have been removed by slope wash. That it really was so removed seems clear, for many, if not all, of these exposures of fresh drift are on slopes, and where the exposures extend up the slopes as along roads one often finds the fresh drift disappearing under a layer of weathered drift higher up. In some places where the road runs along a gentle slope, where it does not look as though much wash had occurred, fresh drift is exposed at the surface on the down-hill side, while on the up-hill side thoroughly leached and oxidized residual till extends to the full depth of the shallow cut. It may be that a relation so obvious appears scarcely worthy of mention, yet it is one that may be readily overlooked in such situations as here where the erosion of the drift occurred before the deposition of the loess, and the latter obscured the slight topographic expression that resulted.

In the cases of the unaltered drift composing the knolls and ridges no evidence other than the freshness of the drift was noted which

might be taken as indicative of their later origin. In these cases it seems that, even if the weathered surficial part has not been removed by erosion, the configuration and structure of the slight elevations may explain their lack of weathering. In the first place, the rounded surfaces of the knolls and ridges rising above the plain shed most of the water falling on them much more readily than do the surrounding plain tracts, especially where the latter have such long gentle slopes such as characterize the area in question. The gravel of the knolls is particularly loose and open so that such of the meteoric water as penetrates, percolates through and out of the gravels very readily and has but a comparatively small contact with the surface of the calcareous particles or pebbles. This is true not only because of the large interspaces allowing rapid passage of water, but also because the total amount of surface exposed by the pebbles is far less than that where the material is finely comminuted as the rock-flour matrix of the till. The result is that while the waters slowly percolating downward into the calcareous till on the plain tract may have relatively large solvent action, so as to remove the finer particles and even the limestone pebbles to the depths indicated above, the limestone pebbles of the knolls and ridges continued unaltered beyond a small amount of cementation in the lower parts of the deposit by lime carbonate carried down from above. On the nearly flat or gently sloping plains surface wash seems to have been reduced to the minimum, while the slow process of leaching out the calcareous elements and oxidizing the ferruginous constituents had its maximum effect. Here the till slowly rotted down. Besides the part which was removed by solution, some of the finest silt may have been carried away by surface wash. This was deposited in the valleys while much of the insoluble part of the clay and the more resistant sand grains and pebbles, the residuum of the leaching process, was left on the unaltered drift.

In those situations, where the topography and the constitution of the drift were such that the rate of leaching and oxidation exceeded the rate of removal of the weathered part by wash, such a residual layer was developed. Where the rate of removal was more rapid or where the two processes nearly balanced each other, fresh drift is exposed at the surface. Where the relations were such that the rate of removal lagged behind the process of alteration, but not so far that

there was time for the reduction of the weathered drift to a residual state, such as seems to have been the case on the moderately mature erosion topography west of Rock River in southern Wisconsin, there is the usual condition of leaching of the clayey and sandy matrix to moderate depths and oxidation only to the degree of changing the original pinkish, bluish, or grayish color to a buff or brownish tint.

It is thus evident that the apparent alteration of a single drift deposit by weathering and erosion may vary considerably in different and often closely adjacent parts of a single drainage basin in the same length of time, even where the differences in elevation are but slight and where the climate is the same. It is true that one cannot always see just what the particular relations were which resulted in the different degrees of alteration at two different exposures, and the observed differences are frequently not just what one would expect from reasoning along the line indicated. However, it is well to bear in mind the fact that such differences do occur where there appears to be no adequate ground for assigning the differently affected deposits to distinct stages of deposition. Caution must be used in applying the criteria and good and sufficient grounds for the differentiation should be observed. It is not necessary to enumerate these criteria in this paper. They have been fully treated by competent authorities in other places. It seems to the writer particularly hazardous to assign a more recent age to what appears to be a thin and scattered deposit of fresh, unchanged, or little altered drift, exposed here and there, when the main deposit of the area in question is of similar lithologic composition and has been considerably altered by weathering and erosion, unless a weathered zone, old soil, or vegetal deposit is observed clearly intercalated between the two drifts. It may not be easy to show that a weathered part has been removed by erosion at the particular places where the fresh drift is observed, or that the conditions for erosion, leaching, and weathering were such that no alteration of the upper part of the drift *in situ* was ever accomplished, but the burden of proof certainly lies with the interpretation which postulates distinct stages of glaciation. Differences in texture and conditions of deposition are particularly unsafe, since almost every conceivable variation of this kind may be found in different parts of what is

unquestionably a single drift sheet. As has been shown in this discussion, careful scrutiny of the topography, the drainage, and other relations which may affect the apparent amount of surficial alteration by weathering and erosion in the area under investigation may yield an adequate explanation of the differing phenomena without the postulation of distinct stages of glaciation.

THE BEARING OF THE STRATIGRAPHIC HISTORY AND INVERTEBRATE FOSSILS ON THE AGE OF THE ANTHRACOLITHIC[1] ROCKS OF KANSAS AND OKLAHOMA[2]

J. W. BEEDE

The present interest in this subject is such as to warrant a brief review of the broader features as determined by the preliminary survey of the data at hand with regard to the age of the Kansas-Oklahoma rocks, before completing the final work upon them, to give an idea of the present status of the problem and suggest some of the larger features to be worked out.

I wish to acknowledge the assistance and co-operation of Professor C. N. Gould and through him of the Oklahoma Survey, which have contributed much to both data and suggestion, as well as material aid in pursuing these studies. For the privilege of carrying on my Kansas studies I am indebted to Dr. Haworth and the Kansas Survey. This manuscript has been submitted to Professors Haworth, Gould, and Prosser for their suggestions and criticisms, which have been incorporated. The general considerations have been freely discussed with Professor Cumings, and he has also read the manuscript and offered valuable suggestions.

In order to arrive at a comprehensive understanding of the invertebrate fauna of the rocks supposed to be of Permian age in the western Mississippi valley it is necessary to understand the stratigraphic history and the nature and range of the faunas of the underlying rocks as well. The discussion of this subject forms a necessary introduction to the Permian question.

[1] This term was introduced by Waagen and he has been followed by Diener of the Indian Survey; it is used to designate the Carboniferous and Permian deposits under a single head, when it is desirable to refer to them in that way.

[2] Published by permission of the state geologists of Kansas and Oklahoma. A portion of this paper was read at the Baltimore meeting of the Geological Society of America.

STRATIGRAPHIC CONSIDERATIONS

Several years ago it was discovered that the Cherokee shales were not the oldest deposits of the western Coal Measures or Pennsylvanian rocks. While it was known that the unconformity between these shales and the Mississippian rocks below was a profound one, yet its true significance was not realized until the discovery in Arkansas and eastern Oklahoma of a great series of underlying rocks of Pennsylvanian—Lower Coal Measures—age. The result of the discovery is to restore the Lower Coal Measures to the trans-Mississippi section, leaving the Cherokee shales and perhaps some associated strata representing the Middle Coal Measures—"Middle Upper Carboniferous" of European geologists—of Europe.

While this latter fact has been determined largely by paleobotanic[1] evidence and that derived from the cephalopods[2] it is believed that the trend of the evidence furnished by the invertebrates is, in general, in the same direction.

The Cherokee shales are a thick (400–500 feet) series of shales with some sandstones and coal, on the whole unfavorable to the existence of clear-water marine faunas. Indeed much of the region stood at about sea-level for considerable lengths of time, as is evident from the plant remains and coal deposits distributed through the rocks as well as by ripplemarks and other physical evidence. However, marine conditions and faunas appeared especially during its later history.

Following the deposition of the Cherokee shales the sea transgressed and the Fort Scott limestone was deposited. This limestone is of considerable thickness and carries a rich marine invertebrate fauna. Following the Fort Scott limestone there occurred rythmic recessions and transgressions of the clearer marine waters throughout the Kansas region, resulting in the deposition of alternate clay shales and limestones with, rarely, fine sandstones and coal. The shales vary from 40 feet to 200 or more feet in thickness, and the limestones from two to 40 or 50 feet in thickness. The shales are clayey, sometimes carrying considerable fine sand, and are gray to

[1] David White, *Mon. XXXVII, U. S. Geological Survey*, 1899.

[2] J. P. Smith, *Mon. XLII, U. S. Geological Survey*, 1903.

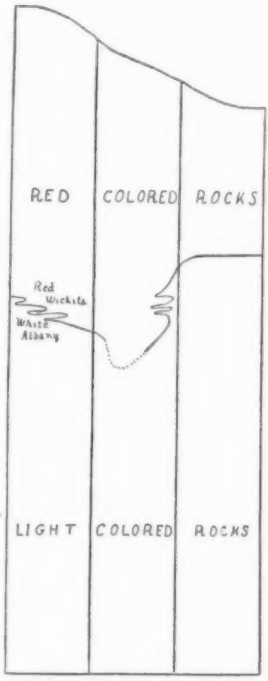
black in color. Blue, gray, and drab are the prevailing colors. The limestones are blue or gray weathering to a buff, and are sometimes nearly white. They are almost invariably well lithified, more or less crystalline, and are not very porous. The thickness of the whole succession, up to the Americus limestone, is over 2,000 feet or 2,500 feet, including the Cherokee shales.

The limestones do not all continue to the southern limit of Kansas, some of them pinching out before reaching the Oklahoma line and others soon after crossing it. Few of them pass beyond the Arkansas River in that state. It seems that the central part of the Kansas basin may have been to the northwestward during later Pennsylvanian time, since the shales frequently become thinner, and the limestones thicker in that direction, though this cannot be said of the lower part of the section. Above the Americus limestone the succession of limestones and shales continues for about 700 feet. However, the shales become more calcareous and marly, the limestones more porous and less crystalline; massive gypsum beds are intercalated, and coal in quantities is wanting. The limestones also weather white.[1] These changes are significant of decided physical or climatic changes, as the local pools of the lower horizons showed no tendency to concentrate and form massive gypsum deposits. Probably, also, the changed aspect of the limestones is indicative of these altered conditions. The first large deposits of gypsum occur just above the Cottonwood limestone in the lower part of the Garrison formation (Neosho member). Above these are the Wreford limestone, Florence flint, Fort Riley and Winfield limestones, heavily charged with chert, and separated by thick layers of shale. The outcrops of these formations form the "Flint Hills" of the eastern part of central Kansas. Over these strata are two soft limestones with three intervening shale beds and a variegated, brecciated, thin limestone. These are grouped in the Marion stage, and end the regular succession of limestones and shales. Over the rocks of the Marion stage lie the Wellington shales, probably several hundred feet in thickness, composed of blue, green, and some red shales. Upon these shales lie 1,400 feet of Red Beds in Kansas. The upper part of the Red

[1] Adams called attention to these lithologic features, in *U. S. Geological Survey, Bulletin 211*, pp. 70–78, 1903.

Beds does not occur in Kansas but is found in western Oklahoma and the Panhandle of Texas.

The whole of the lower succession of shales and limestones forming lowlands and low escarpments divide this section of continuous sedimentation into short stratigraphic units of great lateral extent convenient for paleontologic study.



In Oklahoma different conditions prevailed during much of the time represented by the Kansas deposits, above the Cherokee shales.

Passing from Kansas to Oklahoma the light-colored shales and limestones of the upper part of the Kansas section grade off into red shales and sandstones. The lowest horizon in Oklahoma at which the red sediments predominate is unknown, inasmuch as the strike of the rocks is but little west of south, and the Red Beds protrude eastward in central Oklahoma as a sort of embayment, especially north of the Arbuckle Mountains.[1]

In the region south of the western end of the Arbuckles the Red Beds lie unconformably upon the tilted and eroded Pennsylvanian rocks. It appears that the Albany-Wichita sea of northwest Texas transgressed over this region during a time of slight depression, the waters covering the western end of the Arbuckle Mountains, swinging eastward on their northern slope as far as the Seminole Country. According to Cummins there is no unconformity in Texas between the lighter

[1] For the citation and review of the literature on the Permian of Oklahoma and Texas, see the author's paper on the "Invertebrate Paleontology of the Upper Permian Red Beds of Oklahoma and the Panhandle of Texas," *Kans. Univ. Sci. Bull.*, IV, pp. 115–48, 1907. The geology of the Arbuckle and Wichita mountains is described by Mr. J. A. Taff in *Professional Paper 31, U. S. Geol. Surv.*, 1904.

sediments and the Red Beds, the transition between the Albany and the Wichita being a gradual lateral one. The transgression of the Red Beds in the Arbuckle Mountains may, then, be regarded as a northeastern or eastern encroachment of the Wichita sea—or conditions of sedimentation, as all these beds may not be marine. Whether this Arbuckle unconformity extends northeastward to the easternmost limit of the Red Beds has not yet been determined, and indeed may be very difficult to determine, where the unconformity would resolve itself to a mere disconformity of layers of shales, and perhaps accompanied by a greater or less reworking of the lower deposits. Gould, who has been over this region between the Arbuckles and the Arkansas River many times, states that he knows of no unconformity. If no unconformity exists to the north of the Arbuckle Mountains, it seems probable that the first Permian emergence began here and the deposition of the Red Beds in the Seminole Country is the first record of it, the later sediments from the Arbuckles reaching farther north. Regarding the gradation of the upper part of the Kansas section into the Red Beds in northern Oklahoma, there can be no doubt whatever, and the same is probably true of the central part of the state.

The Arbuckle and Wichita mountains are probably the source of much of the red sediment, in which they are partially buried, and the former mountains are directly responsible for the eastern extension of these beds into central Oklahoma. The extent to which the lighter-colored sediments of Kansas and Texas are replaced by red sediments in Oklahoma and near it, represents in a rough way the limits of the influence of these mountains on the deposits of the time by the spread of their sediments. By the time the deposition of the light-colored sediments had ceased the conditions had become such that nearly all the sediments derived from the land surrounding this basin were red.

In the Oklahoma region the deposition of red sediments began, perhaps, as low as the Howard or Topeka limestones, and perhaps as high as the Emoria or Americus limestones. The deposits then seem to be uninterrupted until the unconformity below the Dockum beds (Triassic) in the Texas Panhandle is reached. Some of these beds appear to be of subaerial origin, as has been shown by Case,[1]

[1] *Bull. Amer. Museum*, XXIII, pp. 659–64, 1907.

while others are certainly marine. Careful petrologic study will probably demonstrate that much of the arenaceous material is wind-blown sediment, more or less reworked by currents or waves as the regions were submerged or flooded. That the sea ever covered the entire area from Kansas to southern Texas and New Mexico at one time may be questioned. If it did, the sediments contained were of such a nature and abundance, or the waters so concentrated as to preclude the free migration of a normal marine fauna throughout the basin. That marine conditions prevailed, at least locally, is demonstrated by the Whitehorse and Dozier faunas.

In Texas normal deposits were laid down in higher horizons than in Oklahoma, and in Kansas there are reasons for believing that the light-colored sediments were laid down at an even later date than in Texas. These conditions are illustrated in the subjoined table, showing a vertical section of the Carboniferous and Permian rocks of the three states.

The extent of this post-Pennsylvania basin seems to have been very great. It included much of Kansas ($\frac{2}{3}$), Western Oklahoma, much of western Texas, and all of New Mexico, Colorado, and Wyoming east of the Rocky Mountain axis. In area it probably aggregated 300,000 square miles.

Together with the varied physical conditions of these three regions went corresponding faunal peculiarities. In the Albany division of the Texas rocks the Pennsylvanian elements of the fauna seemed to persist, while they are largely wanting in their equivalent beds, the Wichita division. A similar thing occurs in the clear-water beds of northern Oklahoma and southern Kansas, north of the Red Beds. Aside from this general fact it should be noted that along the region of the Red Beds and light sediment (litoral?) contact, some of the Pennsylvanian elements of the Kansas fauna persisted much longer than in the same rocks to the northward. The fauna of any given horizon above the Elmdale formation varies very sensibly as we pass from the Nebraska to the Oklahoma line, both in abundance of specimens and species, and in the general aspect of the faunules as well. This is to be expected in the light of the intercalation of massive gypsum beds as low as the lower part of the Neosho member in the northern region. From it we would infer that the waters of the

northern-main marine part of the basin were somewhat more concentrated than at its southern shore.

OUTLINE OF FAUNAL HISTORY

One of the most striking features of the Kansas Anthracolithic fauna is the great range of a relatively large number of species. In regions of instability of the earth each successive change of physical conditions brings in new faunas, tending to eliminate their predecessors, and bringing about more rapid and complete faunal changes than in interior regions of continental stability. In these latter regions the effects of these crust movements are minimized and their effect upon the faunas is proportionally less marked. Consequently one accustomed to the study of the faunas of marginal continental deposits may easily underestimate the value of the less complete faunal changes occurring in rather remote epicontinental basins.

In the regions of great instability it is rarely, if ever, that species show their whole life-history, from its inception to its natural termination, in an unbroken succession of rocks. In an interior region, like the Kansas basin under discussion, persistent species do occur exhibiting this life-history fairly completely, and are significant of the lapse of time represented by the deposits. Many of the forms which are so persistent in the Kansas rocks, especially among the brachiopods, represent the latest stages of the life-history of their genera or families which rarely, if ever, give rise to new phyla, since they have passed their culmination and entered upon their decline. They are therefore not to be expected to give rise to many new forms under ordinary conditions (in the higher deposits) and, having largely lost their adaptability, perish under untoward conditions. Under this class of organisms come the Productidae, Strophomenacea, and Orthidae, and the genera Seminula, Cleiothyris, Hustedia, Ambocoelia, Spirifer, and Pugnax, which are unknown above the Permian. Nearly all these groups have their maximum development in the Pennsylvanian or earlier deposits. Among the bryozoans this is still more strikingly true. The Fistuliporidae, Batostomellidae, Rhabdomesontidae, Fenestellidae, and Acanthocladiidae disappear before the initiation of the Mesozoic, and nearly all of them have culminated before the beginning of the Permian.

In strong contrast with the brachiopods and bryozoans stand some of the pelecypods. They are not paracmic and do differentiate with changing conditions, and constitute the main characteristics of the upper part of the Kansas section. This differentiation seems to have been in the main closely parallel in direction with the development of the Permian pelecypods of Europe.

It is to be regretted that the ammonoid cephalopods were nearly wanting in the Kansas basin throughout its faunal history. The trilobites are represented in the upper rocks by a single species of Griffithides, the last (so far as the Kansas rocks are concerned) of the Proetidae. Many of the ostracods are to be looked upon as degenerate or atavistic, and probably are not found above the rocks of the Chase stage.

The study of the stratigraphy of the Kansas basin and its surrounding deposits and its fauna, has convinced me that the foregoing general considerations must be taken into account in order to reach a rational understanding and interpretation of its faunal history. It should also be held in mind that the evolution of a fauna, in so far as it is capable of evolution, in this great epicontinental sea is of as great significance, as the evolution of a fauna along similar lines about the islands and in the continental seas of Europe. On account of its limitations and relative paracmic condition the latest fauna of the Kansas basin, without free contributions from other regions which physical conditions seemed to prohibit, cannot be expected to contain the wealth of species characterizing cosmopolitan faunas.

In the study of the Anthracolithic section of Kansas the following stages and larger divisions here designated "series" have been made out. These divisions with their characteristic faunas are described in Vol. IX of the Kansas survey, in press at this writing.

The basal formation of the Kansas Pennsylvanian system is the Cherokee shales or Stage A. This stage is characterized by a preponderance of specimens of *Marginifera muricata* with an abundance of *Chonetes mesolobus*, etc. It might with propriety be called the *Marginifera muricata* Zone, as in no other horizon is this species the predominating one. Stage B is characterized by the introduction of a very large number of the most characteristic Coal Measures fossils, sixty species being added in its basal member, the Fort Scott

Series	Stage		
Permian	V	Well.	Wellington shales
		Marion	Abilene conglomerate Pearl shales Herington limestone Enterprise shales Luta limestone
	IV	Chase	Winfield limestone Doyle shales Fort Riley limestone Florence flint Matfield shales Wreford limestone
		J	Neosho member Florena shales } Garrison formation Cottonwood limestone
		I	Eskridge shales Neva limestone Elmdale formation
Pennsylvanian	III	H	Americus limestone Admire shales Emporia limestone Willard shales Burlingame limestone Scranton shales
		G	Howard limestone Severy shales Topeka limestone Calhoun shales Deer Creek limestone Tecumseh shales Lecompton limestone Kanwaka shales
		F	Oread limestone Lawrence shales Kickapoo limestone Leroy shales Stanton limestone Vilas shales Allen limestone Lane shales
	II	E	Iola limestone Chanute shales
		D	Drum limestone
		C	Cherryvale shales Dennis limestone Galesburg shales Mound Valley limestone Ladore shales Bethany Falls limestone
	I	B	Pleasanton shales Coffeyville limestone Walnut shales Altamount limestone Bandera shales Pawnee limestone Labette shales Fort Scott limestone
		A	Cherokee shales

limestone, and fifteen during the rest of the stage. Nineteen of these fossils are among the best-known Pennsylvanian species, such, for instance, as *Campophyllum torquium*, *Rhombopora lepidodendroidea*, *Stenopora carbonaria*, *Chonetes verneulianus*, *Dielasma bovidens*, *Meekella striaticostata*, *Acanthipecten carboniferus*, *Aviculopecten occidentalis*, *Schizodus wheeleri*, *Euomphalus catilloides*, and *Tainoceras occidentale*. One of the peculiarities of this stage is the occurrence of Chaetetes reefs, especially in the upper Fort Scott limestone. Another characteristic is the appearance of Foraminifera with the form of Fusulina, but with imperforate shells, probably belonging to the genus Fusulinella. These conditions maintain themselves until the close of the stage.

These two stages combined make up a definite faunal unit of a larger order which I have designated as "Series I." Fusulinella and *Chonetes mesolobus* are confined to it, and *Marginifera muricata* is never so abundant again. *Chaetetes milleporaceous* is comparatively rare in the rocks above.

The early part of Stage C is marked by another great influx of species which is more continued than that of the preceding stage, though the species are hardly as important. It seems very probable that at this time there was quite as general a sea connection between the Kansas sea and the rest of the world as at any time during the history of the basin. Such important species as *Lima retifera*, *Sedgwickia granosum*, and *Orbiculoidea convexa* are among those introduced—over thirty species in all.

Stage D is the most striking horizon in the Kansas succession. Oölitic conditions with their accompanying fauna invaded the region and give us a peculiar assemblage of fossils, some of which seem quite foreign to their surroundings. We have in the Drum limestone, or its equivalent, at Kansas City and vicinity, a well-developed Pseudomonotis fauna. These fossils usually characterize the Permian rocks of Europe. They are here found in rocks far below the Permian. Unlike the faunas of the rocks above and below, this fauna is strongly molluscan. Many of the species introduced disappeared with the muddying of the waters, while others returned intermittently, especially the species of Pseudomonotis which became very prominent in the Permian rocks.

Stage E forms the closing chapter of the conditions existing in these rocks. Here several of the species with which we have been dealing are found for the last time, examples being *Michilinia eugeneae, Conocardium parrishi, Lima krotowi, Cryptacanthia compacta,* and others.

These three stages make up Series II. It is characterized by the features already mentioned and in a negative way by the absence of species of extreme importance noted below, which occur in the rocks above.

Stage F is characterized by the absence of the species just mentioned and the introduction of *Chonetes granulifer,* one or two species of Enteletes, and the true Fusulinas. Some of these fossils color nearly every faunule of the succeeding rocks of the Pennsylvanian part of the section. Among other important species introduced were the Amblysiphonellas and other sponges, *Limopteria marian,* etc. The top horizon of the stage is remarkable for the last appearance of twenty species, and the first important development of the Fusulinas, a long, slender species, and the first abundance of *Chonetes granulifer.*

In Stage G an undescribed species of Strophalosia is the only permanent addition, while the loss of species amounts to twenty-eight (disregarding species peculiar to the stage), most of these being found for the last time in the Howard limestone, its topmost member. Among these are many prominent Pennsylvanian species, as *Squamularia perplexa, Productus pertenuis, Campophyllum torquium,* etc.

In Stage H, *Sedgwickia altriostrata* is added in the Burlingame limestone and Bairdia, Beyrichiella, and Meekopora appear in the uppermost bed. These latter additions may be well associated with the succeeding stage as they are found in the marly layer resting upon the Americus limestone, and are the precursors of other important introductions which follow.

Stages F, G, and H comprise Series III. From what has preceded it is seen to be characterized by the introduction or development, in its basal part, of three of its main faunal elements and is set off from the succeeding series by the fact that at least one hundred and seventy-five of its species are unknown in the rocks above.

In Stage I four species first appear which play a very important

rôle in the later faunas. They are: *Pleurophorus whitei, Aviculopicten nebraskensis*, and *Myalina permiana* and a species usually referred to *M. aviculoides*. A species of Schwagerina associated rather closely with a Permo-Carboniferous micro-foraminiferal fauna also occurs in this stage. During this stage, too, some of the most characteristic and cosmopolitan species of the Kansas Pennsylvanian are found for the last time. Four of these are: *Spirifer cameratus, Hustedia mormoni, Spiriferina kentuckiensis*, and *Chonetes geinitzi* (not *C. laevis* of Keyes).

Stage J is important in that it records the final reduction of the Fusulinas to the ranks of a rare species, in possessing a very abundant ostracod fauna of a late type, and the final occurrence of ten or fifteen species.

The Chase stage, the upper part of Series IV, is characterized by the development of the pelecypods and the lessening of the rôle played by the Molluscoidea. The abundant forms are: a retrogressive form of *Seminula argentia*, a species of Fenestella, *Productus nebraskensis, Bairdia beedei* or an allied form, with other ostracods, *Septopora* sp., *Derbya multistriata, Mylina permiana, Aviculopecten nebraskensis* and a form of *A. occidentalis, Myalina aviculoides?*, several species referred to Bakewellia, *Pleurophorus whitei*, with two other species, *Pseudomonotis hawni, Edmondia nebraskensis, Aviculopinna knighti, A. nebraskensis*, Producti of the *semireticulatus* type, and a Derbya like *D. crassus* and a species of Rhombopora.

Above Series IV, the brachiopods and bryozoans and ostracods and other lower groups nearly disappear, leaving an impoverished pelecypod fauna. The fauna of the Red Beds of Oklahoma and the Panhandle of Texas, lying one or two thousand feet above the Marion stage, has already been described.[1]

The following table is expressive of the numerical relationship of Series IV to Series I–III:

	No. of Species		No. o Species	Species in Common
Series I	131	Series IV	141	51
Series II	237	Series IV	141	73
Series III	264	Series IV	141	85

[1] "Invertebrate Pal. Upper Permian Red Beds of Oklahoma and Panhandle of Texas," *Kansas University Sci. Bull.*, IV, pp. 115–71, 1907.

These figures are by no means expressive of the faunal character of Series IV, especially the part lying above Stage J. The nature of this fauna is such as to separate it sharply from any Pennsylvanian fauna known to me. For the characteristic fossils of the series as a whole we must add the "Permo-Carbon" micro-foraminiferal fauna described by Spandel,[1] probably from the Neva limestone, *Orbiculoidea manhattanensis*, *Pugnax swallowana* (Hall and Clarke's identity), *Meekopora prosseri*, and *Thamniscus octonarius*.

Considered as a whole the fauna of Series IV, however closely or remotely the individual species may be related to those of other regions, certainly exhibits the same general aspect as the Permian (including the Artinsk and Permo-Carboniferous) of England, Germany, and Russia.

Series IV is regarded as the equivalent of the Permo-Carboniferous of Europe which is classed by most European geologists as the lowest division of the Permian. Stages I and J are, perhaps, debatable ground on account of the great preponderance of Pennsylvanian species. However, the loss of 179 species (two-thirds its fauna) during the latter part of Series III and the introduction of distinctive Permian elements are considered as strong evidence pointing to the initiation of Permian conditions. If this is supplemented by similar plant evidence it should be referred to the Permian.

The Wellington is unquestionably referable to the Permian in the narrowest sense of the word and the Marion probably may be.

THE NORTH URALIAN SECTION

The Anthracolithic section of the Ural-Timen region of northeastern European Russia is as follows: The "Middle Carboniferous," Omphalotrochus horizon, Productus-Cora horizon, Schwagerina horizon, Artinskian, and Permian. The Artinskian constitutes the "Permo-Carboniferous" of Russia. The uppermost division of the Carboniferous is the Schwagerina horizon below which is the Productus-Cora—"Cora" of Tschernyschew—horizon. These two are sometimes referred to as the Fusulina limestone, and the lower as the Gschelian. Below them lies the Omphalotrochus horizon

[1] "Die Foram. des Permo-Carbon von Hooser," *Kans., N. Amer., Abhl. der Naturh. Gesellsch. in Nürnberg*, pp. (on separate) 1–20, 1901.

and beneath it the "Middle Carboniferous." The Artinsk is considered as a subdivision of the Permian.

The part of the section of particular interest to us is the portion including the "Cora," Schwagerina, and Artinsk zones. The relationships of these Upper Carboniferous beds of the Urals to the Artinsk is clear. The sandstones and conglomerates of the latter rest directly upon the calcareous deposits of the former. As has been so well shown by Krasnopolsky, the Permian period of eastern Russia is especially characterized by the uplift of the Ural Mountains from a series of islands to a continuous mountain chain. In the northern part, the Ural-Timen region—including the Timen Mountains—it was rapid and sandstones and conglomerates on the western flanks were the result. This permits a sharp differentiation of the deposits. In the southern region this sharp distinction is impossible as the uplift was very slow and the effects less noticeable, gypsum and dolomites being about the only lithologic indications of the changing conditions in the Donnez basin. In the north there is a sharp differentiation of the fauna in response to the sharply changed physical conditions, while in the south the differentiation is correspondingly more gradual and is produced by the mingling of the northern species of the Artinsk with the open-sea fauna of the Carboniferous. This makes the line between the Permian and Carboniferous harder to draw in the southern region. As Krasnopolsky argues,[1] the place to draw the line is with the first appearance of the Permian species. The conditions in northern Oklahoma, Kansas, and Nebraska were very similar to those of the southern Ural region.

As Rothpletz[2] has pointed out, and as further discussed by Diener,[3] the arenaceous fresh- and salt-water deposits of the Ural-Timen region and the Zechstein are not the normal open-sea deposits of the Permian period, but somewhere those conditions existed in which the percentage of Carboniferous elements in the fauna would be larger. They also point out that these deposits probably are to

[1] *Mem. Geol. Comm. Russ.*, Vol. IX, pp. 506 ff.

[2] Rothpletz, "Die Perm-Trias u. Juraform. auf Timor, etc.," *Paleontographica*, XXXIX, pp. 57 ff., 1892.

[3] "Diener, Himalayan Fossils," *Mem. Geol. Surv. India, Pal. Indica.*, Ser. XV, Vol. I, 1899–1903.

be found in the Asiatic region and in America. To a fair degree this seems to be true of the lower portion of the Permian (that part represented in the Kansas section) in America, and as Diener has shown, in the eastern Himalayas, and it is true of the Mediterranean region. The most typical marine Permian fauna of this age in America is found in the Guadalupe Mountains of Texas and New Mexico.[1] It is the failure to recognize these dual conditions that has caused much of the controversy over the Permian question.

In the Kansas rocks as well as those of Oklahoma and Texas, only the basal part is typically marine. The typical marine facies of the beds extend quite as high in the Kansas section as in that of Texas. Local incursions of marine conditions occur later in western Oklahoma and Texas than in Kansas.

The faunal relationships of the Kansas section are such as to lead us to suspect that an interrupted intermigration requiring considerable time in its consummation occurred between the European and Kansas regions. This fact tends to complicate direct correlation and it is questionable if minor stages can be correlated closely with those of Europe. Less trouble will probably be encountered in the final determination of the separation of the Permian—in the broad sense of the term.

COMPARISON OF FAUNAS

A collection of Foraminifera, probably from the Neva limestone, was studied by Erich Spandel.[2] Some of these were found to be distinctly of Carboniferous and some of distinctly Permian affinities, and he concluded that the rocks from which they come are of Permo-Carboniferous age. He was sufficiently sanguine of this to name two of the species "postcarbonica." The species described are: *Ammodiscus concavus*, *Bigenerina* cf. *eximia*, *Dentalina bradyi*, *Geinitzina postcarbonica*, *Lituola?* sp., *Monogenerina atava*, *M. nodosariforsis*, *Nodosaria postcarbonica*, *Tretaxis conica*, and *Textularia gibbosa*. Probably from the same stratum from which these Foraminifera came, we find specimens of a typical *Schwagerina*. The same stratum

[1] Girty, "The Guadalupian Fauna," *Professional Paper 58, U. S. Geological Survey*, 1909.

[2] *Loc. cit.*

farther south has furnished us with an abundance of Fusulina very similar to, if not identical with, *F. longissima*. It is worthy of note that Schwagerinas and *F. longissima* are associated in some of the European deposits, but among somewhat older faunas. When we consider that Schwagerina is totally unknown in the Atlantic province and consider the route which it must have taken in reaching this region—Eastern Himalayas, China, California—it is but natural to expect it to appear in a somewhat higher horizon than that from which it started, since it is improbable that all the barriers of Eurasia and America were removed to furnish it simultaneous passage. For this reason its appearance among an open-sea Permo-Carboniferous micro-foraminiferal fauna of the Atlantic province may be explained. It should be remarked, however, that some species of Schwagerina are found in rocks of Permo-Carboniferous age in Eurasia.

Of the sponges there are two genera worked out, that permit of direct comparison. They are Amblysiphonella and Steinmannia. *Amblysiphonella prosseri*, from the Topeka limestone in Kansas and a horizon not any higher at Weeping Water, Nebraska, is closely allied to a species from the Lower Productus limestone or Amb beds of the Salt Range in India, while Steinmannia described by Dr. Girty from the Allen limestone seems to have a close relative in the specimens of that genus in the Middle and Upper Productus limestone of the Salt Range. The fact of peculiar interest is that the relative positions of the two in Kansas is reversed from what it is in India, Amblysiphonella occurring at a higher horizon than Steinmannia.

There are two species of corals common to the Kansas section and the Artinskian—Dolomite Suite—of the Donnez Basin of southeastern Russia: *Michilinia eugeneae*, which is confined to Series I and II in the Kansas rocks, and *Lophophyllum profundum*, occurring, probably, throughout the section from Series I to IV inclusive.

Several of our brachiopods appear to have relatives abroad. *Chonetes mesolobus* and *C. laevis* (not *C. geinitzi*) occur in the Schwagerina horizon in the Ural-Timen region, while in Kansas they are confined to Series I, and are separated from Schwagerina by 1,800 feet of deposits. *Chonetes variolatus* and *C. verneuilanis* are found in the Cora and Schwagerina horizons and in the Kansas section are

confined to the rocks below Series IV. *Chonetes granulifer* has a similar range in the Uralian deposits, but begins in the Allen limestone and continues into the Florence flint in the Kansas rocks. *Spirifer cameratus*, *Spiriferina kentuckiensis*, and *Hustedia mormoni* or a near relative of it are found as high as the Schwagerina limestone, and two of them, or their near allies, occur throughout the Artinskian and Permian in Russia. In the Kansas succession Spiriferina reaches the Elmdale formation, and the other two the Neva limestone. Two of them range through the whole Salt Range deposits. *Cryptacanthia compacta* or a species almost identical with it ranges through the Russian deposits into the Artinsk, and is confined to Series I and II of our section. Cleiothysis has a similar range in Europe, throughout the Permian in Asia, and to the Fort Riley limestone in the Mississippi Valley region. Shells of types of *Productus boliviensis* and *P. lineatus* are associated with the rocks from the Allen to the Oread limestone. Their Russian range is from the Cora to the Artinsk inclusive. *Productus cora*, in the strict sense, is probably confined to the rocks below the Deer Creek limestone, and those above are referable to Norwood's *P. pratteni* which continues to the Permian. In Europe *P. cora* ranges into the Artinsk. *Productus gruenwaldti* and *P. punctatus* range through the Artinsk, and are unknown above the Howard limestone of our section. *Productus nebraskensis* is quite as abundant in Series IV as at any horizon below, while (as understood by Tschernyschew) it is confined to the Omphalotrochus horizon.[1] However, its near relative ranges through the Artinsk. *Dielasma bovidens* occurs up to the base of the Wreford limestone and through the Schwagerina limestone of the Urals. The species of Squamularia are hard to differentiate and, with their allies, are ubiquitous throughout Eurasian Anthracolithic rocks. They are unknown above the Howard limestone.

[1] In the original description this species was supposed to be a sharp-beaked form. On the contrary it is an attached form, in its early stages presenting nearly every characteristic of a true Strophalosia, except that the adductor scars are arborescent. Mr. Greene, who is working on this species, has not yet completed his studies and it cannot be stated yet whether this character is a case of parallel development, or whether this is a species of Productus which has taken on the habit of attachment in its young stage. If the latter be true, it is the only case of an attached Productus with which I happen to be acquainted.

Pugnax utah is confined to the Schwagerina horizon on the one hand and in our rocks is ubiquitous, ranging from the Cherokee shales to the Fort Riley limestone. These remarks are also true of *Ambocoelia planoconvexa* which is common to the whole Indian Permian. Our ubiquitous *Derbya crassa* seems to be confined to the Omphalotrochus-Cora horizons. Jakowlew has recently shown that *Meekellia striaticostata* is synonymous with *M. eximia*, which makes it ubiquitous in both Russia and America.

All the pelecypods mentioned below have been found in the Permo-Carboniferous of the Donnez, Oka, and Kljasma basins of Russia as described by Jakowlew. Only their range in the Kansas deposits will be mentioned.

Pseudomonotis is a group of shells for the most part confined to the Permian deposits of the world, though running over into the Mesozoic. Nearly all the known species of it found in America are found in the Drum limestone, Stage D of the Kansas succession. They occur again in the Kickapoo limestone and become especially abundant and characteristic in Series IV and above.

These remarks apply in a general way to *Pleurophorus subcostatus*, the American equivalent of *P. costatus*. *Lima krotowi* or its affine is confined to Stages I and II. *Acanthipecten carboniferus* is confined to Series I and II and Stages F and G, except a specimen found at a much higher horizon in northern Oklahoma last fall. *Entolium aviculatum* has been recorded by Dr. Girty from the Wreford limestone. *Pleurophorus oblongus* has only been reported from the Drum limestone by Dr. Bennett. *Edmondia Nebraskensis* ranges from the Drum limestone well into the upper part of Series IV. *Schizodus wheeleri* is found from the Dennis limestone (and perhaps from the Fort Scott limestone) into the upper part of Series IV. Streblopteria is known from the Drum limestone to the Fort Riley limestone, Dr. Girty recording it from the latter horizon. *Pleurophorus subcuneatus* is unknown below Stage J. The Bakewellias and Cyrtodontarcas have not yet been faunally worked out. A species has been recorded from the Willard shales. However, they are very rare until much higher strata are reached.

It will be noted that in the faunal comparisons and discussions, the Chase and Marion stages have not been treated quite so fully as

those of the underlying horizons. The reason is that the faunules have not been quite so fully worked out and tabulated. However, they have been gone over in a preliminary manner and found to contain nothing, so far as I have observed, that is contradictory to the evidence presented.

From the foregoing discussion of the Kansas faunas and the comparison of the elements in common (for it is largely upon the elements in common that intercontinental correlations must be based) with those of Russia, there seems little reason for considering the Kansas faunas of Series III older than the Schwagerina-Cora horizons of Russia. Indeed the evidence is quite as strong in the opposite direction.

GENERAL SUMMARY AND CONCLUSIONS

From what has been said it is apparent that during the Carboniferous period on the continents of Europe and America there was a long period of time during which favorable conditions obtained and the fauna was relatively varied, but, as many of the genera and species became paracmic, they were, in varying degrees, unable to adjust themselves to the changing conditions introduced more or less gradually with the Permian, and perished. Those capable of least resistance perished first, and in the basal Permian we have a fauna made up of two elements in response to the physical and biologic conditions. First, the hardier forms which had passed their culumation and were on their decline. This is especially true of the brachiopods. They disappeared, not more, perhaps, from want of favorable conditions than from loss of vitality. Second, the pelecypods differentiated—possibly receiving recruits from other regions—and became the characteristic forms of the Permian.

The one part of the Pennsylvanian fauna "grew old and died" assisted by changing conditions, while that part which had not previously reached the acme of its existence differentiated into a fauna capable of inhabiting the more and more concentrated waters of the Permian seas. These classes of organisms being similar on the two continents produced similar results, whether or not the species were identical.

We may now summarize the bearing of the evidence of the stratig-

raphy and the invertebrate fossils on the age of the rocks under the following seven heads:

1. The physical conditions and climatic history of the Permian of America and Europe were similar. They were marked by the deposits of dolomites, limestones, gypsum, and red sediments on both continents.

2. The upper Pennsylvanian sediments were in each case marked by a superabundance of Fusulinas, and by other similar faunal elements.

3. The fauna of the lower Permian—including the Artinsk—is characterized by the development of a peculiar molluscan element and its dominance over the Molluscoidea.

4. The general comparison of the elements in common in the upper Pennsylvanian faunas indicates that Series III is as young as the uppermost Carboniferous faunas of Europe.

5. The great reduction of Pennsylvanian species near the close of Series III and the base of Series IV, together with the introduction of species in the basal part of Series IV which become very important and characteristic elements in the faunas of the higher rocks, seems to justify the provisional location of the Pennsylvanian-Permian boundary at the base of Series IV.

6. The general similarity of the faunas of Series IV and the overlying rocks of the Kansas basin with the Permian of Europe seems to be suggestive of their homotaxy.

7. The extent of Permian time represented in the Texas Panhandle region by the unconformity of the Permian Red Beds and the Triassic Dockum beds is unknown.

What the final evidence of the fossil vertebrates and plants may be remains, to some extent, to be determined. With the rapid progress now being made in the study of the former on both continents and the rapid collection of the plants now in progress in the western Mississippi basin, we may look in the near future to a fuller determination of the homotaxy of American and European Permian. In the meantime I am inclined to take the evidence of the physical conditions and the invertebrate fossils at its face value and draw the conclusions in accordance with it.

PETROLOGY OF THE SOUTH CAROLINA GRANITES[1]

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OUTLINE OF THE GEOLOGY OF THE CRYSTALLINE AREA

The South Carolina area of crystalline rocks extends northwestward from the fall-line, is roughly triangular in shape, and forms a part of the eastern crystalline area which extends southwestward from New York to northern central Alabama.

Until the recently established State Geological Survey of Earle Sloan, this region had received almost no geological study since the state surveys of M. Toumey in 1844–47 (1848 date of final report) and of O. M. Lieber in 1855–60.

The Blue Ridge crosses the extreme northwest corner of the state in a narrow mountainous belt, the higher peaks of which have an extreme elevation of 3,500 feet. Between this mountainous belt on the northwest and the fall-line on the southeast is included the greater part of the crystalline area—the Piedmont province. Its principal physiographic features, in common with the same province toward the northeast and southwest, are the broad rolling upland surface, the valleys carved in the upland, and the minor residuals which rise above the upland. The higher elevations over the region are stated by Sloan to range from 700 to 900 feet above sea-level, with the beds of the major streams averaging 200 feet lower.[2]

Metamorphic crystalline rocks compose the principal part of this region. They include crystalline schists and gneisses derived from both igneous and sedimentary masses, altered chiefly through recrystallization and textural modifications, the most apparent of which is schistosity. The original rocks from which the schists and gneisses are derived are so extremely altered in many places that all trace of their characters is lost.

Among the principal metamorphic igneous rocks are granite-gneisses, hornblende schists, and quartz-sericite schists. In com-

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, p. 505.

position and texture the gneisses indicate derivation from original granites. They are usually of light color, fine- to medium-grained texture, and contain, in addition to quartz and mica (biotite with frequently some muscovite), much microcline and some acid plagioclase (oligoclase). The hornblende schists (amphibolites) are composed usually of hornblende and feldspar (albite and oligoclase), some quartz and titaniferous iron ore, with epidote, zoisite, and in places calcite. The quartz-sericite schists are derived from fine-grained bedded porphyry tuffs,[1] corresponding in composition to granite and quartz monzonite. These altered tuffs have been noted chiefly in the immediate vicinity of the gold deposits of York, Lancaster, and Chesterfield counties, and presumably have large areal extent. Where noted in the vicinity of the gold deposits, their alteration has been chiefly one of silicification and recrystallization.[2]

Metamorphic rocks of sedimentary origin include chiefly quartz schist, quartz-sericite schist, quartz-biotite schist, sericite schist, and crystalline limestone. The limestones are usually associated with the schists into which they may grade along their edges within a short distance.[3] They have been noted chiefly in the northwestern part of the state in Cherokee, Laurens, Oconee, and Union counties, where variation is from ordinary blue limestones to white coarse-grained marbles. True foliation is usually most apparent near the margins or edges of the beds. These limestones are usually magnesian, ranging, according to Sloan,[4] from less than 1 per cent. up to 39.72 per cent. of magnesium carbonate. Ordinarily the blue limestones are the more calcareous and the light-colored ones dolomitic. Other minerals than the carbonates, chiefly silicates (amphibole, pyroxene, and mica) and quartz, are contained in the limestones in places.

Granite, pegmatite, and diabase are the principal unaltered igneous rocks. Their general character and field relations to the surrounding rocks indicate that they were intruded subsequent to the

[1] L. C. Graton, *Bull. No. 293*, U. S. Geological Survey, 1906, pp. 15, 16, 78, 79; Geo. H. Williams, *Journal of Geology*, Vol. II (1894), pp. 28 f.

[2] L. C. Graton, *op. cit.*, p. 16.

[3] *Ibid.*, p. 19.

[4] Earle Sloan, *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 256–61.

principal metamorphism affecting the metamorphic rocks described above. Greatly altered masses of porphyry are intruded into the surrounding schists in places, especially in Chesterfield and Lancaster counties.[1]

The granite and pegmatite are closely related in composition, and each is discussed in detail in the subsequent pages of this paper.

Dikes of diabase, ranging up to 200 or more feet in width, are frequently noted throughout the crystalline region, where they may cut any of the rocks described above. These vary in texture from fine- to moderately coarse-grained, and in composition from olivine to olivine-free rocks, are regarded as Mesozoic in age, and represent the latest intrusions in the region.

At Hornsboro, in Chesterfield County, there is a small area of Juratrias sandstones penetrated by diabase dikes—an extension of the Wadesboro, N. C., area into South Carolina.

The geological structure of the South Carolina crystalline region conforms, so far as is known, with other portions of the Atlantic Piedmont province. The rocks are much folded, having northeasterly strikes, and usually dipping at large angles either to the southeast or northwest.

Very little advance has been made toward determining the age relations of the rocks of this region since the work of the earlier geologists. Lieber[2] regarded the rocks of the King's Mountain region as Silurian. Kerr[3] later assigned the rocks of this area to the Huronian. Becker[4] and Nitze[5] considered the rocks of the central Carolinas to be Algonkian. Williams[6] placed the surface volcanic rocks and their associated tuffs as pre-Cambrian. Recent work by Graton[7] in the King's Mountain region resulted in his assigning all the rocks of the region, except the diabase dikes, "Monroe" beds, and sands of the coastal plain, to the pre-Cambrian. In mapping the "Pisgah Folio" in North Carolina, the extreme southern portion of which includes

[1] L. C. Graton, *op. cit.*, pp. 22, 23.

[2] O. M. Lieber, *Geological Survey of South Carolina*, Vol. III, p. 149.

[3] W. C. Kerr, *Geology of North Carolina*, 1875, p. 133.

[4] G. F. Becker, *16th Ann. Rept. U. S. Geological Survey*, 1895, Part III, p. 260.

[5] H. B. C. Nitze, *Bull. No. 3*, North Carolina Geological Survey, 1896, p. 44.

[6] G. H. Williams, *Journal of Geology*, Vol. II (1894), pp. 28 f.

[7] L. C. Graton, *op. cit.*, 1906, pp. 29–31.

a small part of Greenville and Pickens counties, S. C., Keith[1] refers the Henderson granite to the Archean, the Brevard schists, including fine-grained black and dark schists, with lentils of limestone, to the Cambrian, and the Whiteside granite doubtfully to post-Cambrian age.

Excepting the Whiteside granite mapped by Keith in the "Pisgah Folio" as of doubtful post-Cambrian age, Paleozoic granites are yet unknown in the South. For this reason and because of the absence of definite evidence to the contrary, the South Carolina granites are provisionally assigned by the writer as pre-Cambrian in age.

THE GRANITES

DISTRIBUTION

Granite occurs in each of the twenty-one counties composing the crystalline area described above. During the summer of 1908, quarrying was in progress in nine of the twenty-one counties. The principal producing areas extended southwestward across the state along or near the fall-line in Lancaster, Fairfield, Richland, Lexington, and Edgefield counties, and in the extreme northwest portion of the state in Pickens County. Both massive (even-granular and porphyritic) and foliated (schistose) types of granite are frequent over the crystalline area. These are described in detail in the following pages under a number of individual types based chiefly on differences of physical characters and to a less degree on composition.

MINERAL COMPOSITION

The South Carolina granites—mixtures of feldspar, quartz, and biotite—correspond closely in mineral composition with the granites of the southeast Atlantic states in general. They are prevailingly biotite granites. Muscovite, in association with biotite, is a subordinate constituent in a part of the granites of Edgefield, Fairfield, Oconee, and York counties, and is a principal constituent in a reddish-gray granite found near Liberty Hill post-office in Kershaw County. Hornblende has been met with in the granite of one locality only, namely, one mile south of Winnsboro on the Winnsboro-Rockton

[1] Arthur Keith, *Geologic Atlas of the United States*, "Pisgah Folio," No. 147, 1907, "North Carolina–South Carolina."

road. It is subordinate to biotite but is in sufficient amount to designate the granite a hornblende-bearing biotite granite (p. 742).

The great preponderance of biotite granites over others in South Carolina is shown in the following tabulation:

I. Biotite granite	40
II. Muscovite granite	1
III. Muscovite-bearing biotite granite	8
IV. Hornblende-bearing biotite granite	1
V. Biotite granite-gneiss	14
VI. Muscovite-bearing biotite granite-gneiss	4

The feldspars, as indicated in the table of chemical analyses below, include nearly equal mixtures of potassic (orthoclase and microcline) and sodic-lime (plagioclase) varieties. Microcline is equal to and occasionally greater in amount than orthoclase in some sections, and in others it entirely fails. Microperthite, intergrowths of orthoclase with a second feldspar (albite), is very constantly present. Plagioclase near oligoclase (soda-lime feldspar) is present in large amount, and in most cases is equal to or greater in amount than potash feldspar. Examination of the analyses below brings out this fact of high soda content, which is confirmed by the optical studies of thin sections of the granites.

Besides the principal minerals enumerated above, there occur accessory apatite, zircon, magnetite, sphene, and rutile, together with secondary chlorite, epidote, a light-colored mica, and occasionally some other minerals. These are the usual accessories in granite.

CHEMICAL COMPOSITION

The following analyses give a fair idea of the range in composition of the granites described below.

The chemical composition is characterized by a percentage of SiO_2 ranging from 68.70 to 70.70 per cent., with an average for 17 analyses of 69.46 per cent., which is about the normal silica percentage for granites. Of the 18 available analyses of the South Carolina granites, five show more SiO_2 than is indicated in the maximum percentage (Col. VI, 70.70 per cent.) of the table given on p. 735, ranging for the five from 70.90 to 73.26 per cent. The iron oxides, magnesia, and lime show some variation, but on the whole each is

reasonably uniform, and is neither very high nor very low. Most of the lime in these analyses is to be attributed to the prevailingly large amount of soda-lime feldspar present in the rocks.

CHEMICAL ANALYSES OF SOUTH CAROLINA GRANITES AND GNEISSES*

	I	II	III	IV	V	VI	VII	VIII
SiO_2	68.70	68.80	68.90	69.79	70.54	70.70	69.95	68.94
Al_2O_3	15.49	15.73	15.75	16.08	14.56	15.63	15.19	15.27
Fe_2O_3	1.10	2.14	1.16	1.01†	1.06	1.14‡	1.20	1.80
FeO	3.73	1.57	1.49	1.66†	1.62	1.24‡	1.61	2.04
MgO	0.86	1.16	0.74	0.53	0.78	0.30	0.69	1.04
CaO	1.70	1.64	2.66	1.73	1.28	2.14‡	1.94	2.24
Na_2O	3.09	3.45	4.76	4.07	3.97	3.86	3.91	3.49
K_2O	3.36	4.54	3.49	4.45	5.37	4.76	4.57	4.31
Igni	0.81	0.33	0.18	0.49†	0.27	0.48	0.39	0.29
TiO_2	0.84	0.45	0.36	0.41†	0.60	0.24‡	0.43	0.50
MnO	Trace	Trace	Trace	Trace	Trace	Trace	0.01	Trace
P_2O_5	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
SO_3	0.13	Trace	Trace	Trace	0.06	Trace	Trace	0.02
	99.51	99.81	99.49	100.67	100.11	100.49	99.88	99.92

* Earle Sloan, *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 174-225.

† Average of 2 analyses.

‡ One analysis.

I. Porphyritic biotite granite, Clouds Creek, 4.7 miles north of Batesburg, Saluda County.

II. Biotite granite, Cold Point Station, Laurens County.

III. Biotite granite, Jackson's Quarry, 0.5 mile north of Clover, York County.

IV. Average of 3 analyses, including biotite granite from Anderson Quarry, Fairfield County, biotite granite from Excelsior Quarry, Lancaster County, and biotite granite from Leitzsey Quarry, Newberry County.

V. Biotite granite, Benjamin Quarry, 4 miles east of Greenwood, Greenwood County.

VI. Average of 2 analyses, including biotite granite from Flatrock Quarry, Union County, and Keystone Granite Co.'s Quarry, Spartanburg County.

VII. Average of 13 analyses of biotite granites.

VIII. Average of 4 analyses of granite-gneisses, including Ware Shoals, Laurens and Abbeville counties, Beverly Quarry, Pickens County, Pendleton Quarry, Anderson County, and Bates Quarry, Lexington County.

The sum of the alkalies ranges from 6.45 to 9.34 per cent., with an average of 8.48 per cent. for 13 analyses of the South Carolina granites. In the relation between K_2O and Na_2O the former slightly predominates, ranging from 3.36 per cent. to 5.37 per cent. Na_2O

varies in the analyses from 3.09 per cent. to 4.76 per cent., and may equal or even appreciably exceed (Col. III) K_2O. Na_2O shows a total average for the analyses of 3.81 per cent., and K_2O of 4.33 per cent., a difference or excess of 0.52 per cent. of K_2O. The exact composition of the biotite in these granites being unknown, it is not possible to compute accurately the percentage of potash feldspar from the analyses, but most of the K_2O should be calculated as orthoclase.

In each analysis Na_2O has been calculated as albite, and similarly CaO as anorthite. By adding the albite to the anorthite a soda-lime feldspar is obtained which ranges from Ab_3An_1 to Ab_4An_1 in composition, corresponding to a basic oligoclase. This does not completely accord, in every case, with optical study of the thin sections, which frequently show the presence of microperthite, intergrowths of albite with the potash feldspar, and the undoubted presence of Na_2O in the potash feldspar.

In 13 of the 18 available analyses of South Carolina granites, the percentage of Na_2O approximately equals or is but slightly less than that of K_2O; in 5, Na_2O exceeds K_2O; and in only one is there a considerable excess of K_2O over Na_2O. Molecularly, Na_2O exceeds K_2O in each analysis. On the basis then of essentially equal potash and soda, these granities are, to follow Brögger,[1] quartz monzonites and not normal granites.

In defining the limits of intermediate rock-types between granites and diorites, the range of orthoclase in quartz monzonites is stated by Mr. Lindgren[2] as follows: "In the quartz monzonites I would give this mineral (orthoclase) a range from 20 per cent. to 40 per cent., all in an assumed total of 60 per cent. feldspars. The rocks containing more than 40 per cent. orthoclase would then be classed as granites, there being scarcely room for another family between the quartz-monzonites and the granites."

On this basis it will be seen by reference to the table of analyses that if all the K_2O is calculated as orthoclase, the maximum range in

[1] *Die Eruptionsfolge der triadischen Emptiogesteinen bei Predazzo in Sudtyrol* (Kristiania, 1895).

[2] "Granodiorite and Other Intermediate Rocks," *Amer. Jour. Sci.*, Vol. IX (1900), p. 279.

this mineral would not exceed 32 per cent., and an average would be about 25.5 per cent. The total feldspar content of these granites, based on the analyses above, averages about 66.8 per cent. proportioned about as follows: 25.5 per cent. potash feldspar and 41.25 per cent. soda-lime feldspar.

Attention is further directed in the analyses to the constant presence of titanium in very appreciable amount, ranging in the form of TiO_2 from 0.24 to 0.48 per cent. The microscope indicates its principal sources to be in sphene and titaniferous iron oxides, and to some extent as rutile filaments in the quartz. Manganese and phosphorus are noted, usually in traces only.

TYPES OF THE GRANITES

All the granites are biotite granites, muscovite being frequently present in subordinate amount and hornblende failing entirely except in a single locality. They vary in structure from massive to schistose, and in texture from even-granular to porphyritic rocks, and may be grouped on this basis into (1) even-granular massive granites, (2) porphyritic granites, and (3) schistose or foliated granites—granite-gneisses.

The even-granular and porphyritic granites are textural variations of the same rock-mass and are sometimes indicated in the same quarry, but, in such cases, the porphyritic texture is likely to be of a less emphasized or pronounced type than is observed in parts of Georgia and North Carolina. The granite-gneisses have closely similar chemical and mineral composition to the massive granites, from which they were derived and from which they differ principally, in pronounced schistose structure secondarily induced in them by dynamic metamorphism.

PETROGRAPHY

EVEN-GRANULAR GRANITES

General characteristics.—The even-granular granites have wide but variable distribution throughout the crystalline area of the state. They vary from fine- to medium-grained rocks in texture, less often coarse-grained, and are usually some shade of gray in color—light, medium, and dark blue-gray shades being frequent. In many localities a part of the feldspathic constituent is either of slight or

pronounced red color, which imparts a mixed reddish-gray color to the rock, the depth of which is proportional to the intensity of red color of the feldspar.

The even-granular granites are described below under the following types, based on differences which are best brought out under the individual descriptions: The Winnsboro types (including light gray

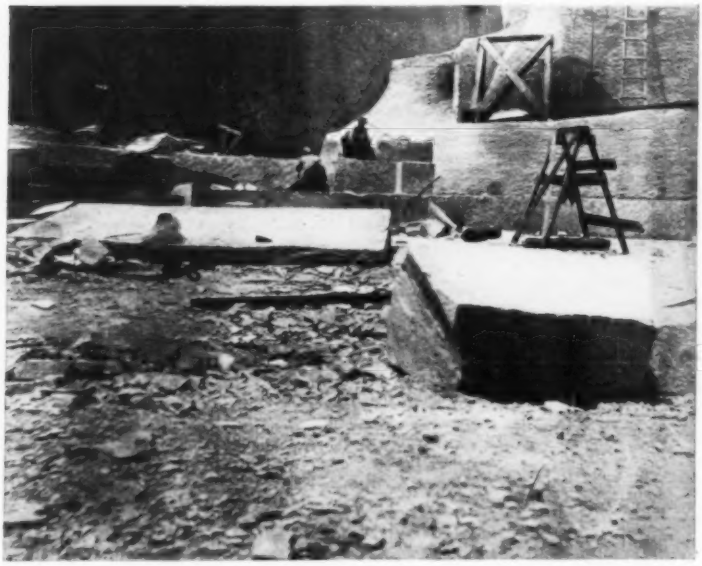

FIG. 1.—Rion Quarry of the Winnsboro Granite Corporation, South Carolina.

and dark-blue gray), the Greenwood–Cold Point gray, the Bowling Green–Clover light gray, and the Columbia red gray.

The Winnsboro types.—The granites near Winnsboro in Fairfield County are of three varieties, which strongly contrast with each other in hand specimens but are essentially similar mineralogically. One of these is a hornblende-bearing biotite granite, described on p. 742, and is more coarsely crystalline than the other varieties, which are biotite granites. Based on difference of color, the biotite granites are known to the trade as (1) the Winnsboro light gray, and (2) the Winnsboro dark-blue gray, the first being extensively quarried

for general building purposes, the latter for monumental stock. These do not differ essentially in mineralogy but bear no resemblance to each other in the hand specimens.

The light-gray variety (Figs. 1 and 2) has no closely similar type, except mineralogically, in the South. Quartz, orthoclase (partly intergrown with albite as microperthite), microcline, oligoclase, biotite, apatite, zircon, and iron oxide, with the usual secondary minerals, make it up. Microperthite and micropegmatite are abun-

FIG. 2.—Near view of a part of quarry face shown in Fig. 1.

dant. Micropoikilitic structure (inclosures of irregular rounded quartz, feldspar, and quartz-feldspar intergrowths—micropegmatite) is rather characteristic of the larger feldspar individuals.

The dark blue-gray variety of fine crystallization has many closely similar representatives, chief among which are the granites of the Excelsior Quarry in Lancaster County and near Newberry in Newberry County, S. C.; the Oglesby-Lexington dark blue-gray granite of Elbert and Oglethorpe counties, Ga.;[1] the Mooresville fine-grained

[1] *Georgia Geological Survey*, 1902, Bull. No. 9A, pp. 188–224; *Amer. Geologist*, Vol. XXVII (1901), pp. 202, 203.

granite in Iredell County, N. C.;[1] and the Richmond-Fredericksburg dark blue-gray granite in Virginia.[2] The granite of the Guilford and Waltersville Quarry near Guilford, Md., is somewhat similar, but is of lighter color and coarser crystallization. As would be expected, these granites may show minor variations in texture and color, but these are so slight that but little difference can be discerned between them in the hand specimens. Orthoclase, much microcline, oligoclase, quartz, biotite, apatite, zircon, and magnetite make up the principal primary minerals composing the Winnsboro blue-gray type of granite.

An average of three analyses of the Winnsboro dark blue-gray type of biotite granite from South Carolina is given below in Col. I and is compared with analyses of the similar type from Georgia (Col. II) and North Carolina (Col. III).

	I	II	III
SiO_2	69.79	69.59	66.01
Al_2O_3	16.08	16.84	17.44
Fe_2O_3	2.85	1.24	5.62
MgO	0.53	0.76	1.11
CaO	1.73	2.67	1.44
Na_2O	4.07	4.77	5.06
K_2O	4.45	4.93	3.16

I. Average of 3 analyses of biotite granite from Anderson Quarry, Fairfield County, Excelsior Quarry, Lancaster County, and Leitzsey Quarry, Newberry County, S. C. *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 252–54.

II. Average of 2 analyses of biotite granite from Diamond Blue Granite Co.'s Quarry, Oglethorpe County, and Hill Quarry, Elbert County, Ga. *Georgia Geological Survey*, 1902, Bull. No. 9A, pp. 191, 241.

III. Biotite granite from Johnson Quarry, near Mooresville, Iredell County, N. C. *North Carolina Geological Survey*, 1906, Bull. No. 2, p. 84.

It will be observed from the analyses that Na_2O and K_2O are essentially equal in the South Carolina and Georgia granites of this type, and in the similar North Carolina type Na_2O greatly exceeds K_2O. Calculating CaO and Na_2O in the analyses to anorthite and albite the following percentages of these minerals are obtained: South

[1] *Journal of Geology*, Vol. XII (1904), pp. 392, 393; *North Carolina Geological Survey*, 1906, Bull. No. 2, pp. 81–85.

[2] *Bull. Geol. Soc. Amer.*, Vol. XVII (1906), pp. 528, 529.

Carolina, 8.62 per cent. anorthite and 35.11 per cent. albite, corresponding to Ab_4An_1; Georgia, 13.34 per cent. anorthite and 40.35 per cent. albite, corresponding to Ab_3An_1; North Carolina, 7.23 per cent. anorthite and 42.44 per cent. albite, corresponding to Ab_6An_1. The ratio of potash to soda-lime feldspar in the Winnsboro dark blue-gray type of granite is: South Carolina, 1:1.7; Georgia, 1:1.9; North Carolina, 1:2.6.

The gray granites from Columbia, Pacolet, and near Carlisle in Union County, S. C., vary from the type of the Winnsboro blue-

FIG. 3.—Bowlder outcrop of the Winnsboro Granite Corporation's light-gray granite at Rion, Fairfield County, S. C.

gray granite chiefly in lighter color and coarser crystallization. Hand specimens of the granite from the different localities contrast strongly with each other in many cases, but they are essentially similar in mineral and chemical composition.

The Greenwood–Cold Point types.—The granites at Quarry in Greenwood County, and at Cold Point farther north in Lancaster County, though essentially similar mineralogically, are of two varieties which bear but slight resemblance to each other in the hand specimens. The granite at Quarry is more coarsely crystalline with bluish opalescent quartz, while the Cold Point variety is more finely crystalline and the quartz varies from colorless to moderately dark smoky in color. The feldspars in both varieties (gray granites) are

of a faint reddish cast which is more pronounced in the Quarry granite. The principal minerals in these granites are orthoclase (partly intergrown with albite as microperthite), microcline, plagioclase near oligoclase, quartz, biotite, sphene, apatite, and zircon, with the usual secondary minerals which result from the partial alteration of feldspar and biotite. Microcline and plagioclase are present in largest amount. Quartz and feldspar are partly intergrown in granophyric structure, indicating overlapping in the periods of crystallization of these minerals. Carlsbad twins of the potash feldspar are noted both in hand specimens and under the microscope.

Chemical analyses of these granites are given in Cols. II and V in the table of analyses on p. 735. The principal constituents in each analysis are here given for convenience of ready comparison.

	Cold Point Laurens County	Quarry Greenwood County
SiO_2	68.80	70.54
Al_2O_3	15.73	14.56
Fe_2O_3	2.14	1.06
FeO	1.57	1.62
MgO	1.16	0.78
CaO	1.64	1.28
Na_2O	3.45	3.97
K_2O	4.54	5.37

A comparison of these analyses shows the Quarry granite to be slightly more acid and to contain about 2 per cent. more of total alkalies. In both, the percentage of K_2O exceeds that of Na_2O by a fraction more than 1 per cent., but molecularly the latter exceeds the former.

The granite exposed along the road one mile south of Winnsboro in Fairfield County varies but slightly from the Quarry type, the principal difference being the presence of additional hornblende to biotite in the former, which is apparent only in thin sections. As previously stated on p. 733, this is the only granite in the state studied by me in which hornblende occurs. Its principal minerals are orthoclase, microcline, oligoclase, quartz, biotite, hornblende, apatite, zircon, sphene, and the usual secondary accessory minerals. A part of the orthoclase is intergrown with plagioclase (albite) as microperthite. Of the feldspars, microcline and plagioclase are

present in largest amount. Micropoikilitic and granophyric structures are common to the feldspars.

The Bowling Green–Clover light-gray granite.—The extensive granite area in the northern central part of York County in the vicinity of Bowling Green and Clover is a medium-textured light-gray biotite granite, closely similar in mineralogy, color, and texture to the Mount Airy granite in Surry County, N. C. It varies from even-granular to porphyritic in texture, but in the porphyritic facies of the rock the feldspar phenocrysts are not very abundant and though frequently of large size, and sometimes showing crystal boundaries, they are usually without crystal outline and grade into the similar ground-mass constituent. In common with the porphyritic granites of the southern states, the feldspar phenocrysts of the porphyritic facies of this type inclose shreds of biotite, equal in size to those of the ground-mass.

This granite consists chiefly of orthoclase, microcline, plagioclase (oligoclase), quartz, biotite, occasional muscovite, together with accessory apatite, zircon, and iron oxide, and secondary chlorite, epidote, colorless mica, and kaolin. Both feldspar and biotite show some alteration in the surface portions of the granite, the former appearing white opaque and chalky from partial kaolinization, the latter showing irregular areas of reddish-brown staining from iron oxide immediately adjacent to the biotite from partial leaching. Intergrowths of orthoclase with plagioclase (albite) as microperthite, and of feldspar with quartz as micropegmatite are frequent. The larger feldspar individuals carry frequent inclosures of feldspar chiefly, quartz, and felsdpar-quartz intergrowths (micropegmatite). Microcline exceeds orthoclase in some sections and is much less in others.

A chemical analysis of this type of granite is given in Col. III of the table of analyses on p. 735. Its close similarity in composition to that of the Mount Airy granite, North Carolina, is indicated in the following analyses, p. 744.

The most noteworthy feature in these analyses is the excess of Na_2O over K_2O. On the basis of the percentages of Na_2O and K_2O in the analyses, the York County, S. C., granite contains 53.41 per cent. of soda-lime feldspar corresponding to Ab_3An_1, and the Mount

Airy, North Carolina, granite, 52.71 per cent. The ratio of potash to soda-lime feldspar in the York County granite is 1:2.6; Mount Airy granite, 1:3.6.

	York County South Carolina	Mount Airy North Carolina
SiO_2	68.90	70.70
Al_2O_3	15.75	16.50
Fe_2O_3	1.16	2.34
FeO	1.49	
MgO	0.74	0.29
CaO	2.66	2.96
Na_2O	4.76	4.56
K_2O	3.49	2.45

The Columbia red-gray granite.—The coarse crystalline red-gray granite quarried at the Smith Branch (County) Quarry, two miles northwest of Columbia, is taken as the type. It does not differ essentially in mineralogy from the gray types described above, although it bears no resemblance to them or to any granites in the other southern states, in the hand specimens. The granite of the Casparis Quarry near Lexington and to the north of Batesburg in Saluda County, S. C., differs from this type only in finer crystallization. In each of these localities the feldspar has pronounced red color, which gives to the granite its characteristic shade. More or less tendency toward porphyritic texture is exhibited in this type of granite. Orthoclase, microcline, oligoclase, quartz, biotite, apatite, magnetite, and the usual secondary minerals are present. Twinning on the Carlsbad law is noted in the potash feldspar. A chemical analysis of this type has not been made as yet, but the thin sections indicate the usual richness in soda-lime feldspar.

PORPHYRITIC GRANITES

Porphyritic granites are common over many parts of the crystalline area in South Carolina, but extensive continuous areas in which porphyritic texture is developed are apparently less frequent than in Georgia and North Carolina. Though porphyritic texture is quite freely developed in many of the granite areas, it either grades within rather short intervals into the more dominant even-granular texture or else is not of so pronounced a type. Like the even-granu-

lar granites into which they grade, the porphyritic granites are biotite granites. The potash feldspar phenocrysts vary in size, form, and color. They rarely exceed 30^{mm} in length, are both allotriomorphic and idiomorphic in outline, white or pink in color, often twinned on the Carlsbad law, contain inclusions of biotite, and are without marked orientation in any of the areas studied.

Two rather unusual types of porphyritic granite in the southern states, the Clouds Creek blue-gray and the Heath Springs coarse gray granite, are described below.

The Clouds Creek blue-gray granite.—This type of granite, occurring in an extensive belt in the southeastern part of Saluda County along Clouds and Moores creeks, does not resemble megascopically the granite of any known locality in the South. In hand specimens it is not unlike the coarse-textured augite-hornblende-biotite syenite found southwest of Concord in Cabarrus County, N. C., but differs from the latter in containing more quartz and in the absence of augite and hornblende.

The rock is a massive porphyritic biotite granite (quartz monzonite) of blue-gray color, the ground-mass of which consists of anhedra averaging in size from 2 to 10^{mm} (quartz, 4 to 10^{mm}, biotite, 2 to 4^{mm}, and feldspar 2 to 10+^{mm}). Porphyritic texture is not very pronounced because of the regular gradation of the feldspar phenocrysts into the similar ground-mass constituent without apparent difference in physical characters shown in the feldspar of the phenocrysts and the ground-mass. The quartz is of slight bluish opalescent color. Feldspar is prevailingly blue gray. In places much of it is nearly white, frequently showing a very faint greenish cast. Cleavage is well developed and Carlsbad twinning is common. The feldspar phenocrysts grade into the ground-mass constituent, are of irregular outline (roughly rounded), from 10 to 25^{mm} and more in diameter, usually blue gray in color though frequently nearly white, highly lustrous and cleavable, and contain inclosures of the ground-mass biotite.

Thin sections show microcline, orthoclase (partly intergrown with albite as microperthite), plagioclase near oligoclase, quartz, and biotite, with secondary chlorite, iron oxide, and colorless mica. Carlsbad and albite twinning are frequent in the feldspars which show some

alteration to a colorless mica and kaolin. Biotite shows partial alteration to chlorite and iron oxide, the latter segregated in the biotite much after the fashion of inclusions.

A chemical analysis of this type, given on p. 735 in Col. I, is noteworthy because it shows nearly equal percentages of Na_2O and K_2O and molecularly the former exceeds the latter. Calculating the CaO and Na_2O to anorthite and albite, a plagioclase feldspar is obtained corresponding to Ab_4An_1, amounting to 33.54 per cent., which exceeds potash feldspar by 13.52 per cent., were all the K_2O calculated as orthoclase.

FIG. 4.—Bowlder outcrop of the Heath Springs coarse-grained porphyritic granite. Three miles southwest of Heath Springs, S. C.

The Heath Springs coarse gray granite.—This variety of granite, exposed in large bowlder outcrops (Fig. 4) several miles southwest of Heath Springs in Lancaster County, is closely similar mineralogically, in texture, and in color to the granite of the Wadesboro-Rockingham area[1] to the northeast in Anson and Richmond counties, N. C. The granite is a porphyritic biotite granite of coarse-grained texture and mixed reddish- and greenish-gray color. The feldspars range from 1 to 25^{mm} in size, are highly lustrous and cleavable, mostly of irregular outline, though in part flat-tabular, averaging about 7^{mm} broad by 20^{mm} long, twinned on the Carlsbad law, and partly reddish and bluish green in color. The feldspar phenocrysts grade into the same ground-mass constituent, thus rendering the porphyritic texture less pronounced, and inclose plates and shreds

[1] *Journal of Geology*, Vol. XII (1904), pp. 385, 386; *North Carolina Geological Survey*, 1906, Bull. No. 2, pp. 15–20.

of biotite. Quartz, 1 to 7^{mm} in size, inclines to moderate dark smoky color, and biotite, 0.25 to 5^{mm} in areas up to 10^{mm} in size.

Its principal minerals are orthoclase, microcline, plagioclase (oligoclase), quartz, biotite, sphene, apatite, zircon, and iron oxide, with secondary chlorite, epidote, a little colorless mica, and kaolin. The thin sections examined showed soda-lime feldspar (oligoclase) in excess of the potash feldspar (orthoclase and microcline). A chemical analysis has not been made of this granite nor of the similar one from the North Carolina area, but the feldspar content is apparently somewhat above the average for normal granites.

GRANITE-GNEISSES

Gneisses of granitic composition comprise one of the principal rock-types in the South Carolina crystalline region. Many of these were derived from original massive granites, and are invariably of the mica type, usually biotite; sometimes subordinate muscovite is associated with biotite. The granite-gneisses are essentially identical in mineral composition (table of analyses, p. 735) with the massive granites, from which the former differ chiefly in the banded structure secondarily induced into them by metamorphism. The principal minerals are quartz, orthoclase (largely microperthite), microcline, plagioclase (oligoclase), biotite, a little muscovite, apatite, zircon, sphene, and secondary chlorite and epidote. Recrystallization and orientation of the essential minerals result in a schistose structure. The gneissic banding may be regular or irregular and contorted, usually the latter; the bands are of varying thicknesses, and are composed of alternating ones of light- (chiefly feldspar and quartz) and dark- (chiefly biotite) colored minerals. Like the massive granites, the gneisses show similar variation in color and texture (even-granular to porphyritic).

The Beverly granite-gneiss.—This type, a contorted biotite granite-gneiss of medium- to dark-gray color and medium-grained texture, resembles quite closely the granite-gneiss of the Lithonia and Odessadale areas in Georgia,[1] and the Rockyface Mountain area, Alexander County, in North Carolina.[2] It is more coarsely crystalline than the

[1] *Georgia Geological Survey*, 1902, Bull. No. 9A, pp. 78, 79, 125 f.

[2] *North Carolina Geological Survey*, 1906, Bull. No. 2, pp. 160 f.

gneiss of the Georgia localities. The minerals are orthoclase, microcline, oligoclase, quartz, biotite, muscovite, sphene, zircon, apatite, iron oxide, and secondary chlorite, epidote, and colorless mica. Orthoclase is partly intergrown with a second feldspar as microperthite. Microcline shows evidence of having been derived in part from orthoclase. Micropegmatite intergrowths as small areas are indicated, and some of the larger feldspar individuals show micropoikilitic structure (inclosures of rounded quartz chiefly). Granulation of the quartz and feldspar is pronounced and orientation of the biotite is usually well marked.

The South Carolina[1] granite-gneiss (Col. 1) is compared chemically with the Georgia[2] gneisses (Cols. 2 and 3) in the following analyses:

	Beverly South Carolina	Lithonia* Georgia	Odessadale Georgia
SiO_2	68.15	75.09	76.37
Al_2O_3	14.30	13.86	13.31
Fe_2O_3†	5.20	.95	1.21
MgO	1.04	.16	0.10
CaO	2.80	.98	1.13
Na_2O	3.80	3.87	4.02
K_2O	3.84	4.87	3.68

* Average of 5 analyses.
† Total iron estimated as Fe_2O_3.

Examination of these analyses shows at once the greater acidity of the Georgia gneisses over the gneiss from South Carolina, in the large excess of silica, and the smaller amounts of lime, magnesia, and iron oxide. In the percentages of alkalies, Na_2O and K_2O, the difference is less apparent. Molecularly, Na_2O exceeds K_2O in each case, but when CaO and Na_2O are calculated to anorthite and albite the difference is more striking. For the South Carolina type total plagioclase is 45.86 per cent., for Lithonia and Odessadale, Ga., 28.05 and 39.10 per cent., respectively. Also, the plagioclase in the Georgia localities is more acid than that from the South Carolina locality.

THE APLITES AND THE PEGMATITES

Aplites.—Aplite dikes are only occasionally met with in the South Carolina granites. They were noted by me only at three localities,

[1] *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, p. 250.
[2] *Georgia Geological Survey*, 1902, Bull. No. 9A, p. 243.

namely, at Smith Branch (County) Quarry near Columbia, the Anderson Quarry in Fairfield County, and at the Casparis Quarry near Lexington. In the quarry near Columbia, aplite dikes are rather numerous, ranging up to four feet in thickness. They are uniformly reddish brown in color and so dense and fine-grained in texture that the minerals cannot be distinguished by the naked eye. The principal minerals, under the microscope, are orthoclase, some microcline, oligoclase, quartz, a little biotite, apatite, and secondary chlorite and epidote. At the Anderson Quarry in Fairfield County, the aplites, ranging in thickness from 1 to 12 inches, are banded with

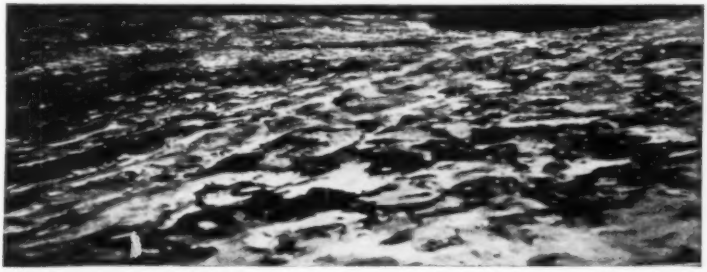

FIG. 5.—Bared slope of granite-gneiss at Beverley Quarry, Beverly, Pickens County, S. C.

pegmatite. They are very fine-grained in texture and of light-gray color, with scant biotite visible to the unaided eye. The minerals are microcline, orthoclase (partly microperthite), some oligoclase, quartz, very little biotite, occasional muscovite, zircon, and accessory chlorite and epidote.

Pegmatites.—Pegmatites are frequent over the region and at times attain considerable size. They are granitic, mineralogically, without unusual or rare minerals observed in them, and may cut any of the rocks of the crystalline complex. The mica is usually biotite with frequently some muscovite associated with it. In the quarry at Pacolet black tourmaline is a constituent of some of the pegmatites.

In Abbeville, Anderson, Greenville, Oconee, and Pickens counties the pegmatite dikes vary from 9 to 20 feet in thickness, and, as indicated in the table of analyses below, the feldspar of these pegmatites is the potash variety.

ANALYSES OF FELDSPAR FROM SOUTH CAROLINA PEGMATITES*

	I	II	III	IV
SiO_2	60.79	62.26	65.60	67.30
Al_2O_3	22.57	20.41	19.45	18.21
Fe_2O_3	0.18	0.31	0.71	0.79
MgO	0.23	0.78	0.13	0.14
CaO	0.24	0.19	0.18	0.14
Na_2O	2.72	1.41	2.02	2.41
K_2O	11.01	12.71	11.34	11.14
Igni.	1.90	1.54	0.63	0.06
TiO_2	.....	Trace	Trace	Trace
P_2O_5	0.09	....	....	....
SO_3	Trace	....	Trace	....
	99.73	99.61	100.19	100.19

* Earle Sloan, *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 142–49.

I. Feldspar from pegmatite dike 8.5 miles southeast of Greenville, Greenville County, S. C.

II. Feldspar from pegmatite dike 12.5 miles northwest of Walhalla, Oconee County, S. C.

III. Feldspar from pegmatite dike 3.7 miles N. 70° W. of Pickens, Pickens County, S. C.

IV. Feldspar from pegmatite dike 6 miles N. 55° W. of Central, Oconee County, S. C.

Several varieties of pegmatite were distinguished by Graton[1] in the tin belt of the King's Mountain area, the four most common of which, in the probable order of their formation, are: (1) Pegmatite, usually of light color and not very coarse grained, composed of microcline, quartz, oligoclase, orthoclase, muscovite, with in places numerous small red garnets and ilmenite. Crushing is apparent in much of the rock. (2) Pegmatite of light color, somewhat foliated, with feldspar as the chief constituent. The feldspar consists of orthoclase, intergrown with albite, and separate small individual grains of albite, quartz, and biotite, with associated small prisms of monazite, and in many places flakes of primary graphite. These are sometimes worked in the western part of Cherokee County for monazite. (3) Pegmatite of very light color and fairly coarse grained, with quartz and feldspar as the only constituents in most places, but muscovite and cassiterite become essential constituents locally. Microcline is abundant, penetrated by grains of albite and slender tongues of

[1] L. C. Graton, *Bull. No. 293*, U. S. Geological Survey, 1906, pp. 20–23.

quartz. (4) Pegmatite of the fourth class is coarse grained and consists chiefly of quartz and muscovite, with feldspar absent or only sparingly present. Feldspar is locally abundant. Cassiterite is an important constituent in places, and spodumene, apatite, and probably lithiophilite are noted.

JOINT SYSTEMS

Two systems of joints intersect the granites in the South Carolina quarries, namely, a vertical set and a horizontal set. These do not in all cases have the same degree of development, nor are the two systems always developed in the same quarry. Vertical joints, the commonest type, may have inclinations of as much as 50° to 60° with variable intervals of spacing. In the northeast quadrant the joints which extend approximately north-northeast and east-northeast are of about equal development; in the northwest quadrant those which extend approximately west-northwest comprise the dominant system. Only a few of the joints measured extended E.-W. and N.-S. The system of horizontal joints, which in general follow the surface configuration of the rocks, is less often developed in the granite of the South Carolina quarries than in the granites of the other southern states.

ELEVENTH SESSION OF THE INTERNATIONAL GEOLOGICAL CONGRESS IN STOCKHOLM, 1910

J. G. ANDERSSON
Stockholm

At the tenth meeting of the International Geological Congress in Mexico, 1906, the Swedish geologists invited the congress to hold its next session in Stockholm, an invititaon that was unanimously accepted. In view of the extensvie preliminary work occasioned by the projected excursions, a wish was expressed by the Swedes that the meeting in question, which should really have taken place in three years' time, might be postponed until 1910. The decision was left to the Swedish geologists, and subsequently 1910 was fixed upon by the Swedish organizing convocation for the meeting in Stockholm.

The initiative in inviting the International Geological Congress to Sweden was taken by the Geological Society in Stockholm on May 4, 1905, when a committee was appointed, which raised the sum required for the undertaking by means of state grants, etc., and issued the invitation on the occasion of the session in Mexico.

A general meeting of the Swedish geologists was held in Stockholm on March 5, 1907, for the purpose of drawing up a general program for the work of organization. This meeting also instructed the previously established committee to officiate as Executive Committee for future arrangements. On the retirement of the former director of the Geological Survey of Sweden, Professor A. E. Törnebohm, his place, as president of the committee, was taken by Professor G. de Geer. The treasurer of the committee is Professor H. Bäckström, while Professor J. G. Andersson, the present director of the Geological Survey of Sweden, officiates as general secretary.

The Swedish Executive Committee considers it advisable that *prejerence* should be given to the discussion of such questions at the meeting of the congress in Stockholm, as the actual geological phenomena of Sweden or of the polar regions can throw light upon. Particu-

lar attention should thus be devoted to the following domains of geological science:

1. *The Geology of Archaean Rocks.*
2. *The Geology of the Quaternary Period.* (Especially climatic changes in late- and post-glacial times.)
3. *The Geology of the Polar Regions.*
4. *Applied Geology.* (Especially extent and distribution of the supplies of iron-ore in the world.)

Numerous, extensive excursions have been planned in connection with the Congress:

Before the Meeting:

1. Northern Sweden. (Norrland.)	
a) Large overthrusts, post-archaean eruptives, etc.	20 days
b) The ore-fields of Gellivare and Kirunavara.	10 days
c) Quaternary formations in Jämtland.	10 days
d) Quaternary formations in Norrbotten.	10 days
2. Spitzbergen.	About 3 weeks
3. Peat-beds in central Sweden.	6 days

During the Meeting:

Several one-day excursions.

After the Meeting:

1. Five simultaneous excursions in Southern Sweden, excepting Scania.	12 days
a) Archaean rocks.	
b) Cambrian-Silurian beds.	
c) Quaternary deposits.	
d) Ores.	
e) General geology.	
2. (To follow 1.) Three simultaneous excursions in Scania.	7 days
a) Cambrian-Silurian beds.	
b) Mesozoic beds.	
c) Quaternary beds.	

The first excursions (to Spitzbergen and Norrland) begin about July 25, the meeting of the congress takes place apout August 18–26, and the last excursions (in Scania) end in the middle of September.

This program is subject to alterations; the present scheme is provisional.

All correspondence having to do with the coming congress should be addressed to the general secretary, Professor J. S. Andersson, Stockholm (3), Sweden.

CLAY DUNES

GEORGE N. COFFEY
Washington, D. C.

Numerous instances of dunes composed of *sand* can be found in almost all countries, especially along the coast or in dry regions where the geological formations are of a sandy character, but dunes made up of *clay* have never, so far as I have been able to ascertain, been reported.

During the last winter the writer was engaged in making a reconnoissance soil survey of south Texas for the United States Department of Agriculture and in the prosecution of the work encountered near the mouth of the Rio Grande some long, narrow clay ridges, the formation of which was at first very puzzling. These ridges were sometimes several miles long, 30 feet high, and not over 200 or 300 yards in width. Occurring in a section of very level, semi-marsh land and being often covered with mesquite, cactus, and palmetto, while the surrounding country shows only a growth of coarse salt grass, they form a very striking feature of the landscape. How had they been formed? To what agency were they due?

One day while driving north of the mouth of the Arroyo Colorado, an old outlet of the Rio Grande, there appeared in the distance what looked to be a mile or more stretch of almost white drifting sand. The soil around was a heavy, marshy clay. On reaching the ridge, which was probably 20 feet high, what appeared, at first glance, to be grains of sand were seen blowing across the bare surface. A closer examination, however, showed them to be granules of clay which could be easily broken down between the fingers and when moistened became very plastic and sticky. Here was the explanation of the formation of these clay ridges; they were really clay dunes.

Further observation showed that these "clay dunes" were almost always associated with a lagoon. Where such relation does not exist at the present time it is doubtless due to the filling of the lagoon by sediments brought down by the river. During dry weather these lagoons become partially or entirely dry, and the mud then cracks

and curls up, giving the wind a chance to get hold upon the material which is then broken up by its action into small grains and driven out upon the surrounding higher land. The wind velocity in this section is rather high and prevailingly from the southeast; therefore the dunes are formed principally upon the northwest side of the lagoons. As soon as the small granules of clay are blown out of the lagoons they encounter vegetation and are stopped. The first rain causes them to break down and coalesce, thus forming a compact mass which is no longer moved by the wind. By this process these clay ridges or clay dunes have been built up many feet above the surrounding lands.

In many instances these lagoons have no outlet and the amount of material in the ridges, if placed in the depressions, would be sufficient to bring them to the level of the surrounding country. It looks very much as if the material forming the dunes had been scooped out and piled along the banks by a great dredge. In fact, many of these depressions have doubtless been formed, or at least enlarged, in just this manner, Nature having hollowed them out with her great scoop—the wind.

These "clay dunes" are confined to the coast country from a point directly east of Raymondville southward to and possibly beyond the mouth of the Rio Grande. They are always found in the low coast country, generally within 5 miles of the Laguna Madre. The question why they occur here and not at the mouth of the Mississippi and other rivers requires some explanation. This will be found, it is believed, in the rather peculiar climate conditions of this section.

A study of the precipitation records in this section will show that the rains are very irregular in their occurrence and that long periods of deficient rainfall may be followed by others of very heavy precipitation. The annual precipitation at Brownsville has varied from 8.88 inches in 1870 to 60.06 in 1886, and the monthly from 0.0 to as much as 30.57. During the long periods when there is little or no rainfall the lagoons nearly all become dry while in a more humid climate, where the rains are more frequent, sufficient time for drying out is not given and no clay dunes are found. The Rio Grande is the only large river in the country where such conditions exist and this is the reason why these clay dunes are confined to this locality.

Reviews

Igneous Rocks. Vol. I, Composition, Texture and Classification. By Joseph P. Iddings. New York: John Wiley & Sons, 1909.

The application of modern ideas of physics and chemistry to the study of the rocks may be seen, more and more, in recent publications, and the results of these newer investigations make it necessary to look at the problems of petrology from an entirely new point of view. It is rather remarkable, and an indication of the need of a systematic presentation of the subject, that within the past few months there have appeared two volumes, following essentially similar plans, and differing entirely from previous works on petrology, namely: Professor Harker's *Natural History of Igneous Rocks*, and Professor Iddings' *Igneous Rocks*.

Professor Iddings introduces the subject with a consideration of the chemical composition of igneous rocks as a whole without regard to the mineral constituents, and he describes the various graphical methods used by petrographers to express the proportions of chemical elements in these rocks.

The magma, solidifying as a rock, takes, in general, the form of a mass of crystals with definite chemical and physical characters, and more or less glass. The relations to each other of the so-called pyrogenetic, or primary, minerals are shown by the presence in them of elements which occur together in the same groups in Mendeléeff's table. Consequently many of the minerals in a given rock are characterized by their content of different amounts of the same element.

The principles of physics and chemistry applicable to rock magmas are fully discussed. Rock magmas are now believed by everyone to be, not simple melts, but solutions of minerals at high temperatures which may act like solutions of other compounds at lower temperatures. In the latter, the reactions taking place, the processes of solidification which convert them into glasses or crystals, and the physical characters and molecular constitution of the liquid solutions are more easily understood than they are in rock magmas at high temperatures and pressures. In order to study properly the facts of physical chemistry, there are discussed the kinetic theory of gases, liquids, and solids, the melting points of rock minerals, and the physical characters and chemical reactions of solutions. After this preliminary statement of principles, the discussion of the chemi-

cal and physical behaviors of molten magmas is begun with the consideration of the chemical reactions which give rise to minerals, and which would probably take place, within the earth, between the elements occurring in igneous rocks. From these studies the laws governing the association of certain minerals in the rocks are deduced.

In consequence of changes of physical conditions, the molten magma separates into solids, gases, and, to a small extent, liquids. These processes are complicated by variable factors such as change of chemical reactions or degree of supersaturation under different conditions of temperature and pressure produced by the movements of eruption. The causes of this separation, the order and the effect of supersaturation upon it, the effect of viscosity upon the rate, and the separation taking place in isomorphous compounds and eutectic mixtures, are discussed.

Following this presentation of the subject of the separation of substances from solution, is a chapter on the crystallization and texture of igneous rocks, the terms used being those recently proposed by Cross, Iddings, Pirsson, and Washington.[1] The degree of crystallization of a rock magma and the amount of glass affect both the mineral constituents of the resulting rock and its texture. The extent of crystallization, the magnitude, shape, and arrangement of the crystals or amorphous parts, and the factors which influence texture are fully described and illustrated.

The differentiation, or splitting-up of a homogeneous rock magma into chemically unlike portions, is next considered. The evidences of such separation are divided into two groups: (1) Igneous rocks differing in chemical composition in different parts of the same body; and (2) igneous rocks of different compositions associated in regular manner with reference to place of occurrence and time of eruption, and possessing such chemical characteristics that their previous existence as components of a homogeneous magma is clearly indicated.

The agencies which are likely to affect the character of a rock magma are changes of temperature, pressure, or gas content, and Professor Iddings considers the way in which each of these may act upon certain physical or chemical characters of the magma. They may change the density of the liquid magma in certain parts and produce convection currents, or they may change the viscosity and modify the diffusivity. A change in osmotic pressure would produce a variation in the molecular concentration in different portions, a change in saturation or chemical equilibrium would affect the crystallization and the resulting minerals, and a change in the character of the solidification would affect the texture of the rock. The

[1] *Jour. Geol.*, Vol. XIV, 1906, pp. 692–707.

chapter closes with a brief sketch of various hypotheses that have been suggested in explanation of differentiation, and a statement of the processes of magma eruption.

A discussion of structures and the modes of occurrence of extrusive and intrusive igneous rocks concludes part one. By the term structure, Professor Iddings follows the more recent usage, restricting it to those "large features of rock bodies which have been produced by cracking, by fracturing and aggregation, or which may be brought about by erosion," the term texture being applied to the microscopic features.

The second part of the volume, which consists of 121 pages, is taken up with nomenclature and classification of igneous rocks. After a short historical sketch, the author presents an adaption of the current qualitative systems of classification. The definitions of the rocks are essentially those of Rosenbusch and of Zirkel given in terms of mineral composition and texture with no expression of views as to the possible genetic relations between them. Professor Iddings divides the rocks into five groups based on the dominance of (1) quartz, (2) quartz and feldspar, (3) feldspar, (4) feldspar and feldspathoid, (5) feldspathoid. Each of these is separated into divisions based on the character of the preponderant feldspathic constituent, and these, in turn, into divisions with little or much ferromagnesian minerals. The final divisions are into phanerocrystalline and aphanitic rocks; the latter having two subdivisions, those of cenotypal and those of paleotypal habit.

The last chapter of the book, consisting of 61 pages, is taken up with the quantitative classification of Cross, Iddings, Pirsson, and Washington, and is an abridgment of the system published by them in 1902.[1] The rules for the calculation of the norm have been rewritten and are now much clearer than formerly, the explanatory notes interpolated in the older work being omitted.

It is only in this second part of Professor Iddings' book that it differs widely from that of Professor Harker. In both books the treatment of the newer petrology is similar, but the two writers differ entirely upon the question of classifications, although they agree that the existing systems are unsystematic, unsatisfactory, and confusing. Professor Harker has given but 18 pages to classifications, and one could wish that he had further developed his own ideas on the subject, especially in the way of a classification based upon eutectics, such as was suggested by Becker[2] and Vogt.[3]

[1] *Jour. Geol.*, Vol. X, 1902, pp. 555–690.

[2] Geo. F. Becker, *21st An. U. S. G. S.*, III, 1899–1900, pp. 519, 520.

[3] J. H. L. Vogt, "Ueber anchi-eutektische und anchi-monomineralische Eruptivgesteine," *Norsk Geol. Tidsskr.*, 1905, Vol. I, No. 1.

It is his view that "the establishment of a genetic classification is dependent only on a fuller knowledge of facts and principles," and "a systematic treatment of igneous rocks on these lines . . . . is not to be expected in the immediate future." Professor Iddings has made no attempt at a genetic classification, believing that there are too many factors influencing genetic relations to permit of their use. He thinks that the chemical composition of an igneous rock is "its most fundamental character . . . . and is therefore of greatest importance for its correlation with other igneous rocks."

Professor Iddings' book is a most valuable addition to the literature of petrology and will be welcomed by students for its presentation of the new view of those problems which, to a large extent, have heretofore been given only in scattered publications, representing the work of such men as Day and his colleagues in the Geophysical Laboratory, Doelter, and Vogt.

The book is well printed on good paper, the half-tones are clear, and the line drawings are neat. The book is bound in blue cloth uniformly with the same author's *Rock Minerals*.

A. J.

Through the Yukon and Alaska. By T. A. RICKARD. I–XIII, pp. 384. San Francisco: Mining and Scientific Press, 1909.

Few if any travelers in Alaska have made so many and such accurate observations as Mr. Rickard, and of those who have published similar journals, no one has included so much of real value to those interested in the resources of the Yukon district and Alaska, or in the mining activities of those countries. The author has told in a delightful way many of the incidents of travel, and has taken pains to give accurately the history of some of the most remarkable discoveries in these northern countries. The romantic history of the Treadwell mines, the discovery of gold on the Klondike, the wonderful development at Fairbanks, and the story of the discovery and exploitation of the Nome beach, are here given in a fuller and more interesting way than they have elsewhere appeared. Mr. Rickard has retold many of the stories associated with life in Alaska, during the exciting periods from 1895 to 1900: thus the fake discovery of a Silent City, the story of Soapy Smith and his gang of desperadoes, the incidents associated with the great stampede over White Pass and Chilcoot Pass, the life at Dawson, on Cleary Creek, and the story of many events at Nome which have afforded material for novels and magazine articles, are given in a very readable form. The book is, however, more than a

narrative of travel, for the author has described the mining conditions and mining processes with an ability that few can equal. The book is well illustrated and a very welcome addition to the literature on Alaska.

W. W. A.

Schistosity by Crystallization. By FRED. EUGENE WRIGHT. *Am. Jour. Sci.*, Vol. XXII, September, 1906.

The schistose and gneissose textures of many metamorphic rocks have been ascribed to the orienting influence of pressures with a stress difference acting during the recrystallization of the rock in its new environment—solution taking place along the line of greatest strain and deposition along the line of least resistance and normal to the maximum stress. In such cases the rock cleavage is due to the parallel arrangement of its mineral components in planes perpendicular to the line of greatest stress.

Conditions of experiment in which crystallization under unequal strains could take place were effected by using cubes of glasses made by chilling melts of different minerals rapidly, and by heating these to the point at which crystallization first began, the viscous glass at that temperature being still in a state of fair rigidity, and capable of supporting a certain amount of unequal strain. Textures similar to those of certain metamorphic rocks were produced in this way, and an experimental confirmation of the theoretical deductions thus obtained.

Quartz as a Geological Thermometer. By FRED. EUGENE WRIGHT AND ESPER S. LARSEN. *Am. Jour. Sci.*, Fourth Series, Vol. XXVII, p. 162.

This paper, which is a review and discussion of experiments made by the writers in the Geophysical Laboratory of the Carnegie Institution at Washington, is an important contribution to the knowledge of mineral genesis. By means of the electric resistance microscope the birefringence and circular polarization of quartz plates at various temperatures were measured and the inversion point (575°) was accurately determined.

The birefringence of the quartz plates decreases gradually from 0° to 575°, at which point the decrease is very rapid. Beyond this point the birefringence increases slightly. The inversion was observed both on heating and cooling and the changes are constant and sharply marked. There is also a marked change in the angle of circular polarization at the inversion temperatures and abrupt change in the coefficient of expansion

which is expressed both on heating and cooling and a change in the heat capacity.

Quartz formed at the low temperature is hexagonal and trapezohedral-tetratohedral, while that formed at the high temperature is probably hexagonal and trapezohedral-hemihedral. It is found that these crystallographic relations are expressed in the circular polarization of the two varieties. Intergrowths of right- and left-handed quartzes are more frequent and more regular in boundary lines in the quartz formed at low temperatures and the etched figures show more regular and more sharply defined twinning. Quartz formed at the higher temperatures and subsequently cooled may show the effects of inversion by shattering or latent weakness inherent in such crystals may be disclosed by etching in hydrofluoric acid. Large clear quartzes free from cracks have probably never reached the inversion temperature.

Quartzes from veins and geodes and certain vein pegmatites are in general clear and free from intricate fracture-cracks and show regular intergrowths of right- and left-handed quartzes; they are frequently twinned and the outline of the twinned areas is usually regular. The quartzes from graphic and granite pegmatites, granites, and porphyries are smaller in size, frequently fractured and cracked. They rarely show intergrowths of right- and left-handed individuals and the outlines of such intergrowths may or may not be regular. The observed characteristics of the first group of quartzes are those deduced theoretically for low-temperature quartzes, while the features of the second group are those deduced theoretically for quartzes formed above 575°. This places the temperature of final solidification of an intrusive granite mass above 575°.

It is hoped that these investigations will be extended to the quartz formed by contact metamorphic processes. As pointed out by Lindgren these deposits without doubt were formed above the critical temperature of water. By the use of the quartz thermometer on carefully selected material the precipitation point of many minerals of the contact zones could be approximated much more closely than has yet been done.

Tridymite, it is pointed out, forms at 800°, beyond which the high-temperature quartz is unstable. Definite data concerning the behavior of SiO_2 through a wide range of temperatures and at ordinary pressures are thus supplied. Perhaps the pressures do not greatly affect the nature of crystallization though they do affect the solubility of quartz. In the great majority of the rhyolites and quartz-porphyries of Montana, Nevada, and Colorado, it is, in the experience of the reviewer, the most conspicuous of the phenocrysts. Nearly everywhere it is resorbed. The phenocrysts

of quartz were clearly formed before the magma rose to the surface and their corroded or embayed condition is due to resorption by the magma. It is generally assumed that the relief of pressure causes a change in equilibrium and as a result of relief the magma ceases to precipitate quartz and dissolves some of that which has been precipitated. Does the presence of quartz instead of tridymite show that the temperature of solidification was less than 800°? In the case of granitic rocks where the last crystals formed are an eutectic, the temperatures there are low, but in the porphyries containing resorbed quartz the latter must have been present in excess of the eutectic for the temperature and pressure prevailing at the time.

If the pressures do not seriously affect the quartz thermometer then it follows that the excess quartz in porphyries (phenocrysts) does not begin to be precipitated until the lava has cooled to 800°. From this and the great abundance and wide distribution of the resorbed quartz phenocrysts, it follows that the siliceous lavas probably rise to the surface very slowly—so slowly that the large quartz crystals may be precipitated and again resorbed while the lava which ultimately solidifies as a glassy rock has cooled to 800°.

If calcite, pyrite, or some other common vein mineral should supply another point near 100° C., certain vexed problems related to the genesis of an important class of metalliferous deposits could easily be solved.

W. H. E.

Seventeenth Annual Report of the Ontario Bureau of Mines, 1908. Published by order of the Legislative Assembly of Ontario. THOS. W. GIBSON, Deputy Minister of Mines, Toronto, 1908.

The report includes a statistical review of the mineral productions of Ontario for 1907, technological and geological notes on various mines by E. T. Corkill, a description of the geology of Thunder Bay–Algoma Boundary by Arthur S. Parsons, of the Iron Ranges east of Lake Nipigon by A. P. Coleman and E. S. Moore, and a review of the iron and steel industry of Ontario by George Cleghorn Mackenzie.

The value of the mineral production for 1907 was $25,019,373.00, an increase of 12 per cent. over 1906. Six metals yielded nearly fifteen million dollars. These, in order of their value, are silver, iron, nickel (ore value), copper, cobalt, gold. The non-metallic products yielded above ten million dollars.

The splendid showing is due chiefly to activities in silver mining at Cobalt, which produced $6,301,095.00 in silver, cobalt, arsenic, and nickel.

At this camp four companies have installed concentrators to treat the low-grade ores.

The nickel ores yielded $2,271,616.00, but the product had a refined value of nearly four times that sum. Nearly all of this production was recovered by two companies. About a million dollars' worth of copper was recovered as a by-product of the nickel ores, and the Superior and Bruce mines produced also a relatively small amout of this metal.

W. H. E.

Epitome of the Economic Geology of New Mexico. By FAYETTE A. JONES. Published by Direction of the New Mexico Bureau of Immigration, Albuquerque, New Mexico, 1908.

This well-arranged, neatly bound volume of 47 pages is sure to meet with the favor of prospectors and others interested in the mineral resources of New Mexico. The minerals and other products of present or prospective economic importance include coal, copper, silver, gold, lead, zinc, iron, manganese, molybdenum, fluorite, alum, salt, gypsum, sulphur, mica, asbestos, meerschaum, turquoise, graphite, petroleum, natural gas, guano, marble, stone, clay, and mineral paint. A feature of the booklet is a catalogue showing the distribution of various minerals.

W. H. E.

Recent Publications

—Gilmore, C. W. Osteology of the Jurassic Reptile Camptosaurus, with a Revision of the Species of the Genus, and Descriptions of Two New Species. [No. 1666. From the Proceedings of the United States National Museum, Vol. XXXVI, pp. 197–332, with Plates 6–20. Washington, April 17, 1909.]

—Glangeaud, Ph. Deux curieux volcans de la chaine des Puys, le Puy Chopine, et le Puy des Gouttes. [Extrait des comptes rendus de l'Association Française pour l'Avancement des Sciences. Congrès de Reims, 1907. Paris.]

———. L'allier miocène. Un gisement de vertébrés miocènes, près de Moulins. [Gauthier-Villars, imprimeur-libraire des comptes rendus des séances de l'Académie des Sciences. Décembre, 1907.]

———. Les éruptions de la Mimagne. Sept périodes d'activité volcanique du miocène inférieur au pleistocene. Les éruptions pliocènes et pléistocènes de la Limagne. [Gauthier-Villars, imprimeur-libraire des comptes rendus des séances de l'Academie des Sciences. Paris, mars, 1908.]

———. Sur l'extension des dépressions oligocènes dans une partié du massif central et sur leur rôle au point de vue hydrologique. [Gauthier-Villars, imprimeur-libraire des comptes rendus des séances de l'Académie des Sciences. Février, 1908.]

———. Sur quelques tremblements de terre dans le massif central et sur leurs relations avec les dislocations anciennes. [Extrait des comptes rendus de l'Association Française pour l'Avancement des Sciences. Congrès de Reims, 1907. Paris.]

—Goldschmidt, V. and Wright, F. E. Ein Projections-Transporteur. [Sonderabdruck aus Zeitschrift für Krystallographie usw., XLV. Band, 6. Heft. Leipzig, 1908.]

—Graton, L. C. The Production of Copper in 1907. [U. S. Geological Survey. Advance chapter from Mineral Resources of the United States, Calendar Year 1907. Washington, 1908.]

—Green, J. F. N. The Geological Structure of the St. David's Area. [From the Quarterly Journal of the Geological Society, Vol. LXIV, August, 1908.]

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ERRATUM

Page 24: *Quercus milleri* sp. nov. preoccupied by a species described by Ettingshausen. Should read *Quercus calvertonensis* sp. nov.

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